

Original article

Spatial distribution, determinants, and implementation barriers of green-blue-grey infrastructure-based urban heat island mitigation strategies in Budapest, Hungary

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ABSTRACT

Urban nature-based infrastructure is increasingly recognised as a powerful tool to tackle climate change-induced challenges. However, knowledge gaps remain regarding the use of hybrid infrastructure in heat mitigation, including context-specific factors that impact efficacy. This is particularly true in Budapest, Hungary, where between 1902 and 2019, a 4°C difference in urban heat levels was observed. This study aims to systematically evaluate where the urban heat island effect is most significant, what factors influence the urban heat island effect, what barriers exist to installing and scaling mitigating infrastructure, and what governmental levels and organs, civil society actors, and private actors are involved in urban heat mitigation efforts. Using an online survey ($n = 216$), key informant interviews ($n = 13$) and transect walks, findings show residents perceive the most important factors green surface size (98.7 %), water bodies (87.7 %), structural materials (92.9 %), construction materials (70.8 %), building types, density and surface albedo/colour (68.8 %), and domestic cooling (60.4 %). The heat-affected areas of Budapest include the dense historic core, outer industrial belt, railway stations, and Liszt Ferenc Airport. Key barriers relate to limited space, political will, funding, as well as unfavourable legal frameworks and bureaucratic environments. Moreover, a lack of vertical and horizontal coordination results in a disconnect between stakeholders' agendas and understanding of the issue. Opportunities lie in expanding green spaces, improving rainwater management and retrofitting building structures through improved insulation. Further priorities include reducing impermeable surfaces and increasing the proportion of cool roofs and other hybrid infrastructure. In parallel, advancing knowledge of public acceptability of government policies and of societal responses to these policies is needed. This requires robust, transparent information dissemination and consultation mechanisms to foster legitimacy and trust. Finally, ensuring accountability across all levels of governance, with clearly delineated responsibilities to monitor progress and adaptive management, is essential for responding effectively to evolving social-ecological conditions.

1. Introduction

In recent decades, the growing prevalence of urban heat islands (UHI) has emerged as a pressing environmental, social, health, and economic challenge for cities worldwide (Pörtner et al., 2023; Tong et al., 2021). UHIs refer to densely structured built-up areas where temperatures are significantly higher than in surrounding rural regions (Oke, 1983, 1982, 1978). As urbanisation accelerates at an unprecedented rate, urban areas are responsible for more than 70 % of greenhouse gas emissions and over 75 % of energy consumption, contributing

to increasing temperatures (Khor et al., 2022). Moreover, the dramatic alteration of surfaces (Ucal and Xydis, 2020) and material composition of the urban fabric combine to create unique microclimates (Giyasova, 2021) and shift hydrological flows (Xu et al., 2023). Meanwhile, intensifying heatwaves, extreme weather events, and rising temperatures all bear the unmistakable fingerprints of climate change: mounting heat-related mortality rates (Ballester et al., 2023), rising sea levels (Nerem et al., 2018), and increased frequency and severity of floods (Bronstert, 2003) and droughts (Verstraete et al., 2008). Currently, over 50 % of the world's population lives in cities, and this proportion is set to

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surpass 70 % by 2050 (Moreno et al., 2016). Here, climate change affects an estimated 85 % of the global population (Callaghan et al., 2021; IPCC, 2023). In this context, evidence is needed of how urban forests and other vegetation support climate adaptation (Han et al., 2025; Mumtaz, 2024; Rosenzweig et al., 2018).

In general, urban heat is a well-researched field, where the causes, geometry, relative intensity, and effective mitigation measures are routinely addressed. Besides building density, urban heat is influenced by factors such as urban geometry, wind speed (Oke, 1988, 1981; Rajagopalan et al., 2014), vegetation, water cover (Doick et al., 2014; Ogashawara and Bastos, 2012), city size, population density (Kotharkar and Surawar, 2016; Landsberg, 1981), proportion of artificial and natural surfaces, permeability, albedo (Dian et al., 2020; Taha et al., 1988), and air pollution (Liang et al., 2021; Arnfield, 2003; Oke, 1982). Factors such as street orientation and width, building height and geometry significantly influence street-level airflow and solar access (Deilami et al., 2018). Anthropogenic heat emission of cities' building stock and energy consumption also influences the diurnal pattern of heat stress (Sailor, 2011). However, existing research has not investigated where urban heat islands are most intense across cities. Much research is done remotely, even though urban heat is highly contextual, dependent on human-nature interactions and behaviour, highlighting the need for more in-situ analyses (Masson-Delmotte et al., 2018; Xu et al., 2023).

Globally, studies have found that the use of urban green spaces (Abdulateef and Al-Alwan, 2022; Costanzo et al., 2016; Li et al., 2024; Musco, 2016) and water bodies (Ferdowsi et al., 2024; Hathway and Sharples, 2012; Yang et al., 2016) have a cooling effect, help manage stormwater flow (Almaaitah et al., 2021) due to permeable surfaces (Nguyen et al., 2019), enhance albedo (Degirmenci et al., 2021) and reduce mortality rates (Iungman et al., 2023). Urban green infrastructure includes tree canopy, green open spaces, green roofs, and vertical green systems (Azmeer et al., 2024). Blue infrastructure includes lakes, rivers, canals, fountains, and urban wetlands (Ferdowsi et al., 2024). Grey infrastructure for heat mitigation can include high albedo surfaces, such as cool roofs (Wang et al., 2022), building materials with improved heat retention and insulation (Apritasari et al., 2024). Hybrid infrastructure – multifunctional combinations of green, blue, and grey infrastructure – includes public shading, green roofs and walls, and permeable surfaces (He et al., 2023). Blue-green hybrid infrastructure has been shown to have a positive impact on the physical and mental well-being of residents (Csóka, 2023; Han et al., 2024).

In Budapest, various studies have characterised the UHI effect, where a 4°C difference in urban heat levels between 1902 and 2019 was observed (KSH, 2023a). The foundations of UHI-specific climatological research in Budapest were laid down by Probáld (1974). Since UHI research became mainstream in the early 2000s, numerous studies have been published by researchers of the Hungarian Meteorological Institute and other research institutions (e.g. Centre for Energy Research) and universities (e.g. Budapest University of Technology or Economics, Eötvös Loránd University). These analysed city-wide characteristics of UHI formation (Dian et al., 2020, 2019; Göndöcs et al., 2017; Gyulai, 2016; Li et al., 2020), borough-specific variances in UHI intensity (Frickle et al., 2014; Incze et al., 2018; Pongrácz et al., 2017, 2016), heatwaves and heatwave vulnerability (Buzási, 2022; Dezsó et al., 2022; Révész, 2008), the impact of anthropogenic heat emissions on UHI formation (Bohnenstengel et al., 2014; He et al., 2007; Sailor, 2011; Shahmohamadi et al., 2011), and the influence of surface albedo (Pongrácz et al., 2022). Despite the proliferation of Budapest-specific research on the UHI effect, there remains a lack of attention given to how those findings could be translated into policy and practice. To the authors' knowledge, as of 2025, no publicly available studies have assessed what measures need to be prioritised in tackling soaring urban temperatures.

Moreover, the effectiveness of urban blue and hybrid infrastructure for UHI in Budapest remains under-researched in contrast to relatively well-studied green infrastructure (Dian et al., 2020; Göndöcs et al.,

2017; Gyulai, 2016; Li et al., 2020; Pongrácz et al., 2022; Probáld, 2014; Révész, 2008). While Oláh (2012) discusses green-blue hybrid infrastructure, there has been no Budapest-based study that also includes the use and potential of grey infrastructures. Finally, although the risk of heat has been recognised by various prominent organisations – e.g. World Health Organisation (Mudu et al., 2023), Environmental Protection Agency (2012), National League of Cities (Pine et al., 2023), European Centre for Medium-Range Weather Forecasts (ECMWF, 2023) –, several obstacles hinder effective translation of research and international guidelines to local policymaking and implementation.

In this paper, the potential of urban green, blue, grey, and hybrid infrastructures to mitigate the UHI effect in Budapest, Hungary is systematically investigated. To address existing research gaps, this study seeks to answer the following questions: (1) What factors influence the formation and intensity of UHIs and where is the UHI effect most significant across the city? (2) What is the effectiveness of installing, maintaining, or expanding green, blue, and grey infrastructure for mitigating UHIs in Budapest? (3) What are the barriers to installing and scaling UHI-mitigating infrastructure in Budapest? (4) What is the role of governments, civil society, and private actors in mitigation efforts? As such, this is the first work to empirically confirm the distribution of impact, barriers to implementation, and effectiveness of blue, green, grey, and hybrid infrastructures for UHI mitigation in Budapest. The findings of this study offer policy and planning guidelines, focusing on UHI mitigating infrastructures in Budapest and other (peri-)urban centres.

2. Methodology

2.1. Study site

In addition to being the political, administrative, economic, and cultural capital of Hungary, Budapest (47°29'33"N, 19°03'05"E; Fig. 1, Table 1) is one of the largest cities in Central Europe with 1,67 million inhabitants with an area of 525 km² – and is home to a fifth of Hungary's population (Frickle et al., 2014; KSH, 2023b). Since the mid-1800s, when urban population growth first began to accelerate in Budapest, and especially following the 1989 regime change whereafter urban sprawl became more pronounced (Kovács et al., 2019), protecting green spaces has become a major challenge (de Linares et al., 2018). The complex topography of Budapest allows for the observation of a wide range of microclimatic conditions (Fig. 2) within a small, contained area (Probáld, 2014). Such versatility makes it an ideal platform for the exploration of various mitigating strategies and an example that could inform UHI policies in other cities around the world.

Crossed by the Danube River in a North-South direction, the city is divided into the western part of Buda and the eastern part of Pest. Pest has an urban structure of concentric zones. The city centre is surrounded by a dense inner residential belt; a transitional zone (historically used for industrial, transportation, storage, and military purposes, now at various stages of transition toward tertiary and residential functions), and an outer residential belt of former suburbs, dominated by detached family houses with small- to medium-sized gardens (Szczuka et al., 2022). The opposite side, where Buda is located, is characterised by the Buda Hills, rising from 96 m (Danube) up to 527 m (János Hill) (TessaDEM, 2024). Although the hilltops and the upper parts of the slopes are mostly covered by recreational forests, the lower parts of the slopes are interspersed with up to five-storey houses and villas, surrounded by green areas. High-density residential areas are generally confined to the foothills and the minor plains adjacent to the Danube.

Over the last decade, the immediacy of the impacts of climate change on the city and its residents has become increasingly apparent (Pongrácz, 2021). The months of June and July 2023 were the hottest on record – both globally (Copernicus Climate Change Service, 2023) and in Budapest (Bodnár, 2023). Although Budapest's Climate Strategy (Tatai et al., 2021a) recognises the increasing severity of UHI formation and its

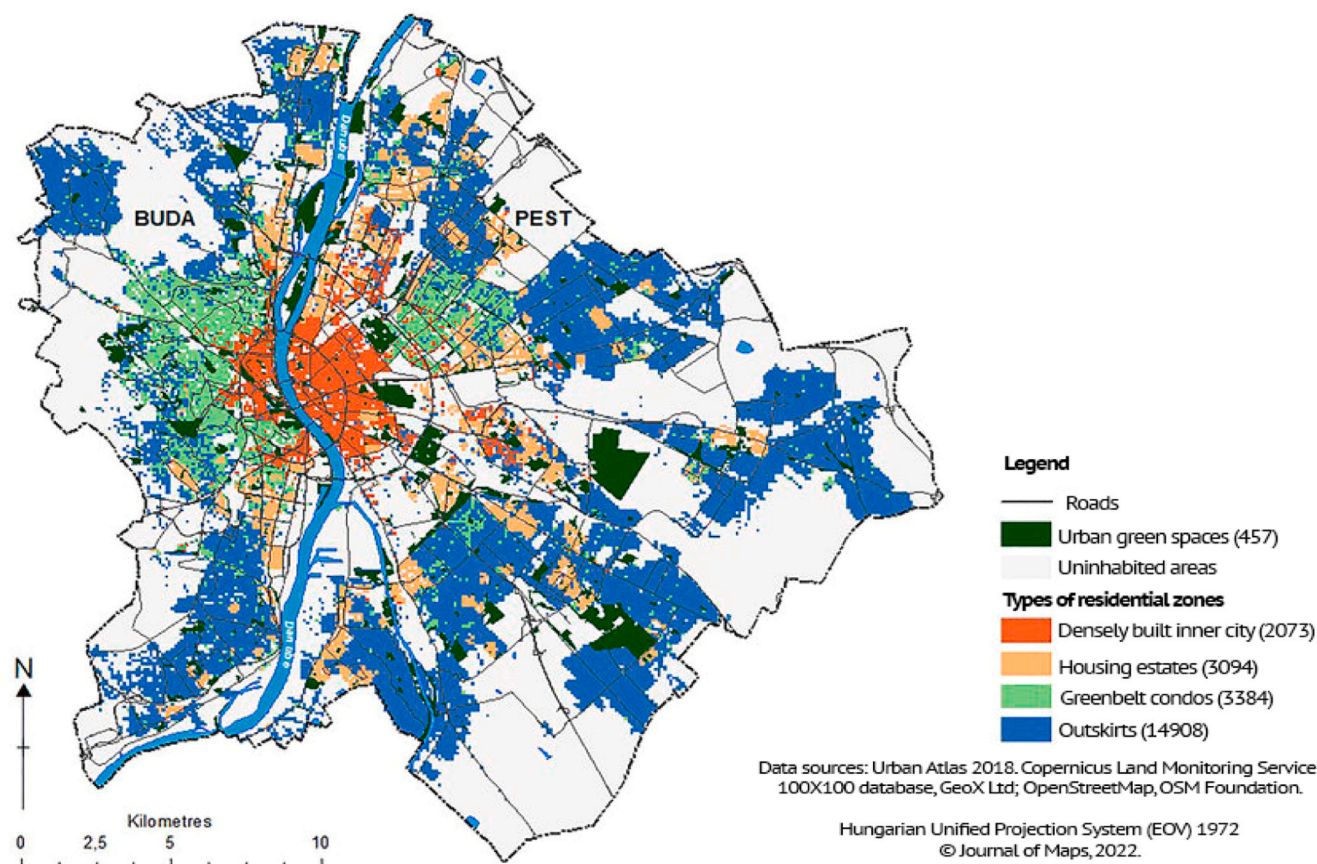


Fig. 1. Green spaces, uninhabited areas, and residential zones of Budapest (Farkas et al., 2022).

Table 1
Climate and land use in Budapest (KSH, 2023a; Ute et al., 2013).

Climate	Climate	Humid sub-tropical
	Average annual precipitation (mm)	514.5
	Mean annual sunshine (hours)	2,196 (2003–2020)
	Annual mean temperature (°C)	12.7 (2003–2020); 13 (2022)
	No. of heat days (30 +°C) per annum	34 (2003–2020); 48 (2022)
	No. of days affected by heatwaves per annum	21 (2003–2020); 32 (2022)
Land use		
	Built-up	44 %
	Water	3 %
	Forest	14 %
	Park & other green space	5 %
	Agriculture	12 %
	Transport	18 %
	Other	4 %

impact on citizens' well-being, the municipality's current list of UHI-focused mitigation strategies is wanting. The UHI-mitigating capabilities of green infrastructure are only mentioned as side effects, and there are but two UHI-focused solutions mentioned: 'A8: Protection of ventilation corridors to ensure adequate air-space ratio' and 'A9: Promotion of the use of climate-friendly building materials and technologies' (Tatai et al., 2021a, p. 89). The present study proposes additional mitigation strategies that could be utilised in combination with those already included.

2.2. Data collection

2.2.1. Semi-structured interviews

Semi-structured interviews ($n = 13$; Fig. 3) were conducted between

June and July 2023 with active professionals who have expertise in relevant disciplines, such as environmental policymaking, urban planning, and urban climatology. Respondents represented academia, government, activists, and the private sector, using stratified sampling across gender, sector, and age. All were Budapest-based and had expertise or lived experiences of the social-ecological impacts of urban heat. Candidates were recruited via e-mail or through mobile phone. After being piloted and adapted, interviews lasted between 52 and 126 minutes and were conducted in Hungarian, which were then translated into English. Interview consisted of 22 questions (Appendix 1) and were approved by the Ethics Committee of the University of St Andrews, adhering to protocols of anonymity, consent and voluntary participation.

2.2.2. Online survey

An online survey ($n = 216$) was administered in the same period. The survey, comprising 71 questions (Appendix 2), aimed to uncover the public perception of the UHI phenomenon and public opinion of UHI-mitigating strategies, policies and action plans for Budapest. Participants were recruited via online social media platforms (Facebook and Instagram), making use of groups to share academic surveys – using snowball sampling (Parker et al., 2019). This approach facilitated reaching people of a diverse range of backgrounds. The survey was designed and administered using Qualtrics XM.2.3. Analysis.

For narrative situational analysis, interviews were first translated into English, then transcribed and cleared of filler and double words. The resulting transcripts, along with notes of key insights taken during interviews, were inductively coded in NVivo (v.1.7.1). Results of the online survey were analysed in Qualtrics XM to provide both comparative and illustrative statistical data.

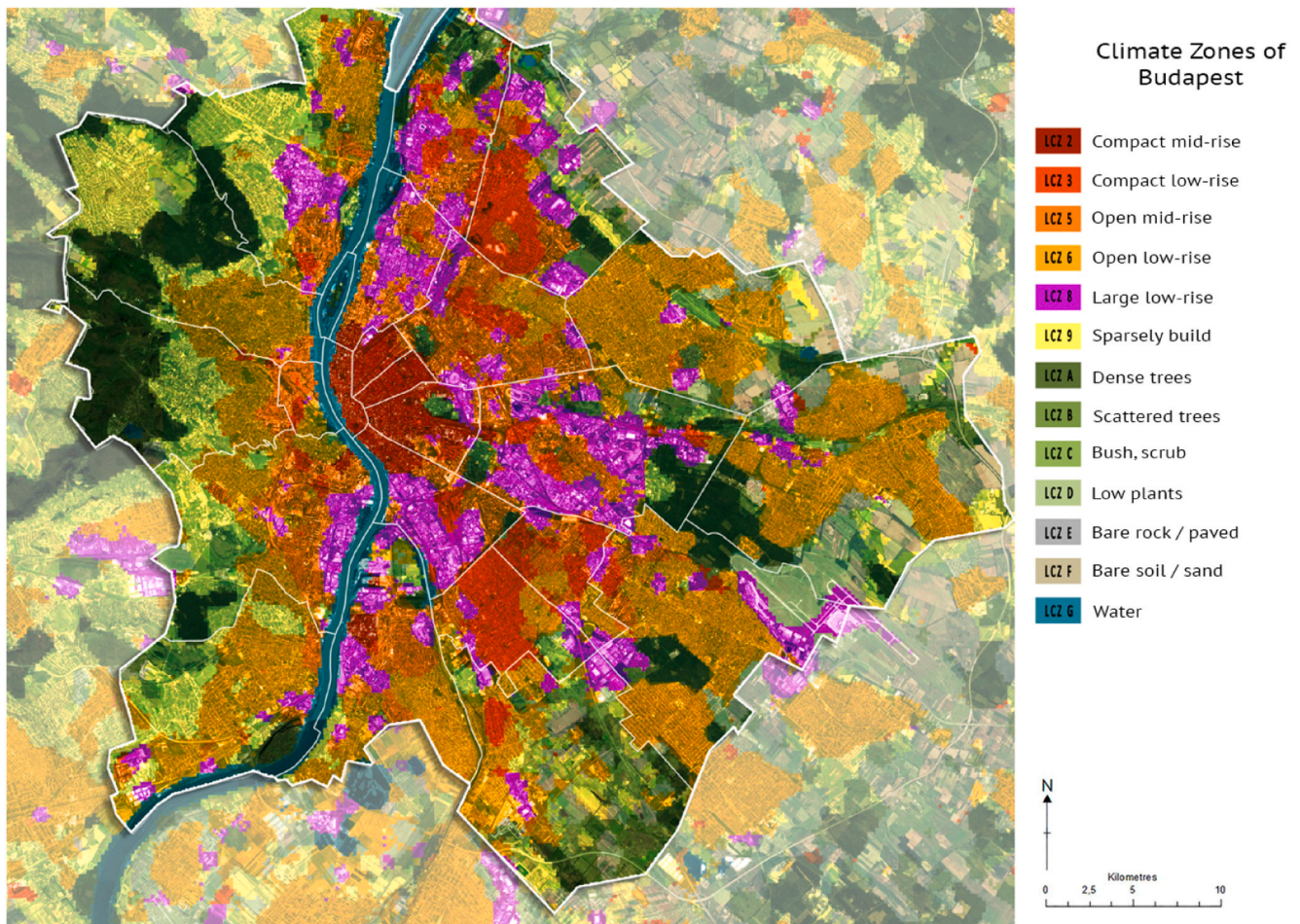


Fig. 2. Map of the climate zones of Budapest (Szczuka et al., 2022).

2.3. Limitations

First, the mode of participant recruitment for the survey is likely to have introduced some selection bias towards younger generations, with a mean range between 25 and 29 years (Fig. 4) and against persons without internet access or social media profiles, or from households and areas of lower income. Yet, in the absence of information on respondents' economic situation, the possibility of means-based selection bias cannot be confirmed. Second, neither the online survey nor the sample size of the interviews qualifies as representative. Of a population of Budapest (1,67 million), to achieve a 95 % or 99 % confidence level with a 5 % margin of error, the ideal sample size would be at least $n = 385$ or $n = 663$, respectively. Third, people who are interested in and supportive of UHI mitigation initiatives will generally be more inclined to respond to the online questionnaire. Due to this confirmation bias, critical or opposing views are inevitably underrepresented, thus skewing results. However, the high agreement of different data sources and the similarity of the findings to previous research suggest that the insights gained from the research can still be considered valid. Fourth, certain historic and geographical features, as well as unique legal, regulatory, and governmental characteristics of Budapest, limit the paper's transferability to other contexts. Finally, data collection occurred in June – July 2023, which were the hottest months on record (Bodnár, 2023; Copernicus Climate Change Service, 2023). The impact of the short-term effects of the heatwave may have amplified the public's perception of UHI.

3. Results

3.1. What factors influence UHI formation, and where is the effect most significant?

According to online survey respondents, the principal causes of UHI formation and intensity in Budapest can be broken down into two categories: physical qualities of the urban fabric, in terms of green surfaces size (98.7 %), structural surface materials (92.9 %), the size of water bodies (87.7 %), construction materials (70.8 %), building types (68.8 %) and density, surface albedo or the colour of surfaces (68.8 %) and texture of surfaces (47.4 %), as well as human activities, including domestic cooling (60.4 %), heating (37.7 %), cooking, and transportation (Fig. 5).

Cities' physical organisation affects their mesoclimatic characteristics. Budapest is characterised by narrow streets with climatically unfavourable geometry and orientation. The absence of continuous wind channels parallel to main wind streams leads to poor ventilation, which increases heat retention. All interview participants agreed that the most severely affected areas of Budapest are the historic parts of the city, the inner area of downtown Pest, the outer industrial belt, as well as in-city factories, depots, railway stations, and Liszt Ferenc Airport. Moreover, due to the city's dense structure, there is a lack of space to install and maintain vegetation, resulting in insufficient cooling, shade, and air filtration. This is coupled with an abundance of artificial surfaces with low albedo and limited permeability, such as dark concrete walls, asphalt-covered roads, tiled or pebble-dash roofs, and paved open spaces. These artificial surfaces lead to high heat absorption, poor water

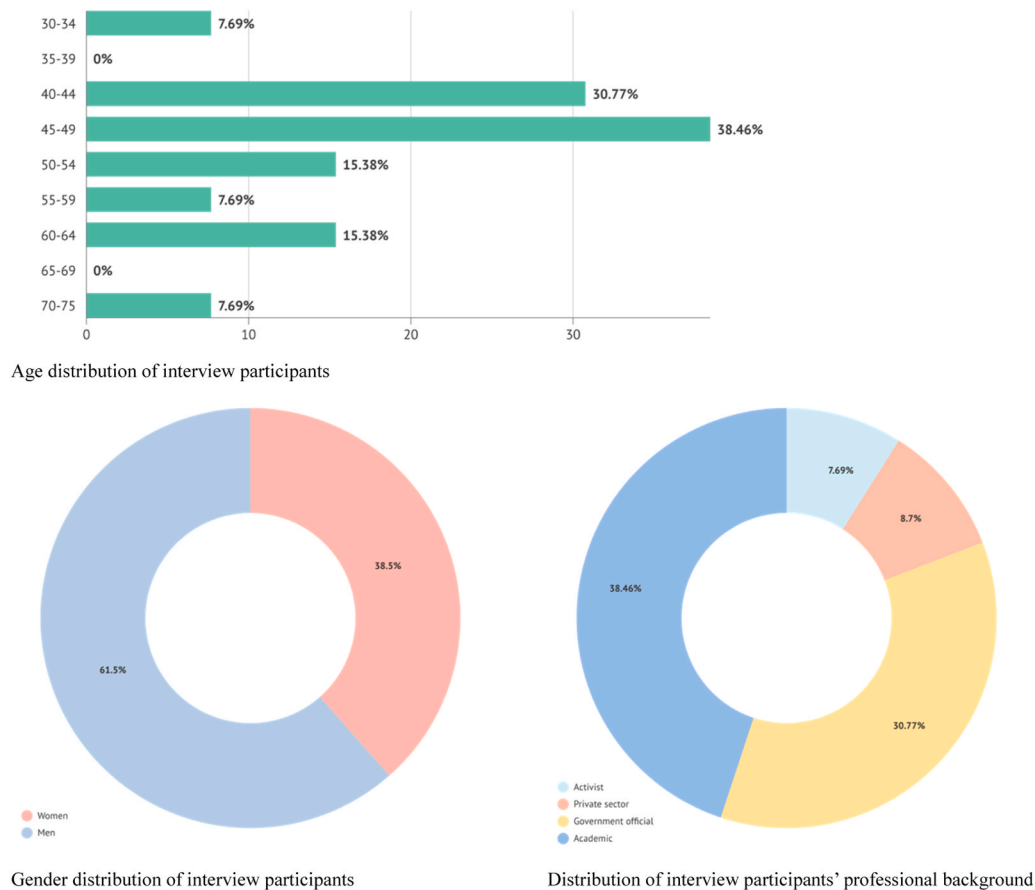


Fig. 3. Demographics of interview participants (n = 13) showing the distribution of their age, gender and professional representation.

retention, and limited evapotranspiration. Old, inefficient, and deteriorated insulation technologies also contribute to anthropogenic heat emissions.

In terms of human activities, modern urban lifestyle is concomitant with ever-growing anthropogenic heat production. Key contributors include a 70 % surge in residential air conditioner use in 2020 (Major, 2021) and a 2–4 % annual increase in private motorised transport since 2014 (Tatai et al., 2022). The growing preference for cars over active mobility amplifies heat and pollutant emissions (Tatai et al., 2021a), along with inappropriate infrastructure use, such as running air conditioning, heating with open windows, or neglecting shading measures, further exacerbates heat island formation.

3.2. What is the effectiveness of UHI-mitigating infrastructure in Budapest?

78 % of interviewees rejected one-size-fits-all solutions for UHI mitigation, emphasising the need for strategies tailored to local conditions (e.g. building types), priorities (e.g. most significant UHI contributing factors), opportunities (e.g. tenders, coordinating urban planning efforts), and barriers (e.g. regulations safeguarding public utilities, uneven distribution of benefits). The remaining 22 % favoured prioritising green infrastructure, such as trees in public squares and streets, urban meadows, groves, and forests, above other strategies.

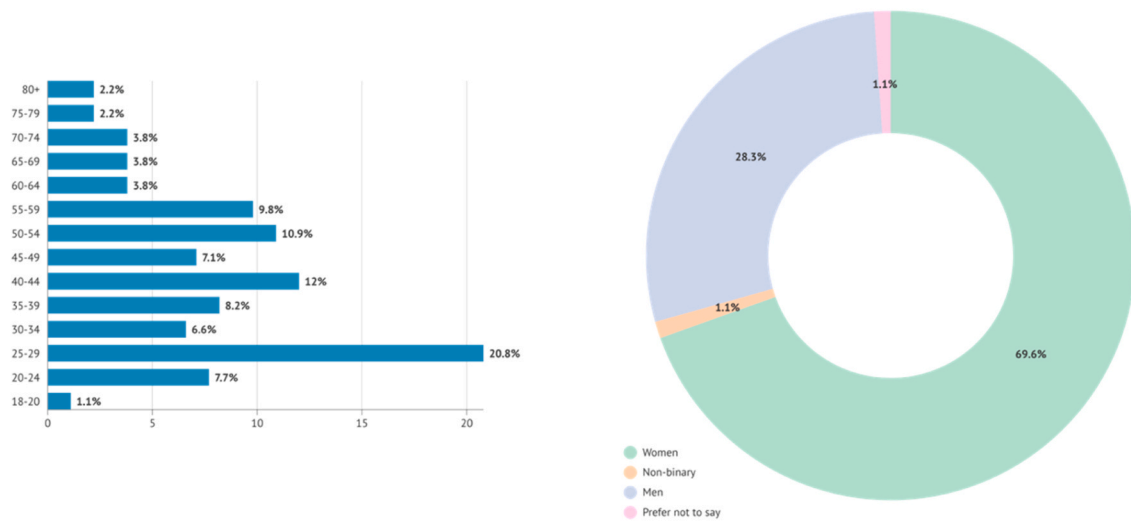
Respondents agreed that hybrid approaches offer the highest mitigation potential. To exemplify this impact, a participant managing the green office in a Budapest borough reported that trials involving modified roof surface materials – such as green and cool roofs – achieved surface temperature reductions of up to 10°C. Another participant from a Budapest-based sustainable architecture and urban design research organisation highlighted that, according to the organisation's findings,

green-blue-grey hybrid infrastructures can reduce daytime ambient urban heat by 5–10°C, depending on their size and complexity. The condition of these systems is important; several participants studying UHI-mitigation strategies emphasised that neglected, abandoned, or scorched lawns provided virtually no ambient cooling benefits due to the absence of evapotranspiration and lowered albedo.

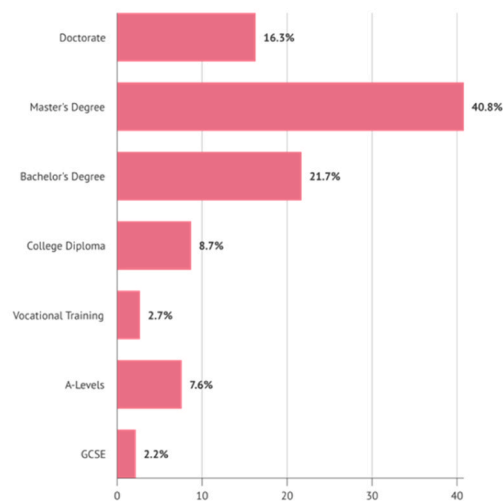
Urban blue infrastructure, such as fountains and spray gates, contributes to localised cooling through evaporation. While Budapest is divided by a substantial body of water, a professor at the Hungarian University of Agriculture and Life Sciences noted that, despite its size, the Danube has limited cooling capacity. Unlike extensive forests, such as those in the 12th borough's hills (Frickle et al., 2014; Mokhtari et al., 2022), which act as effective heat sinks, the Danube absorbs heat during the day, only to re-emit it at night. This process leads to a delayed heating effect, amplifying night-time UHI intensities, rather than providing consistent cooling.

3.3. What are the barriers to installing and scaling UHI-mitigating infrastructure in Budapest?

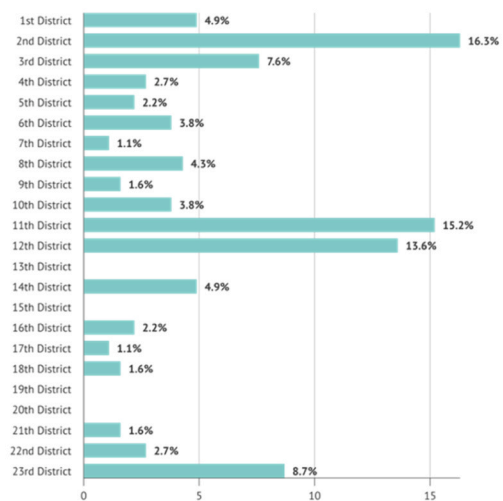
Although the need to tackle increasing urban heat levels in Budapest has generally been recognised by its Climate Strategy and Action Plan for Green Infrastructure Development (Tatai et al., 2021b), several obstacles hamper mitigation efforts. According to participants, physical barriers related to limited space availability, poor soil quality, weak building structures, and unfavourable roof geometry. Non-physical barriers relate to a lack of available funding, political willingness, awareness and priority, complicated bureaucratic environments, unfavourable legal frameworks and planning rules, implementation and enforcement challenges, and the limited acceptance of nature-based solutions.

Age distribution of survey respondents ($\bar{x}=29$; $SD=16.30$)

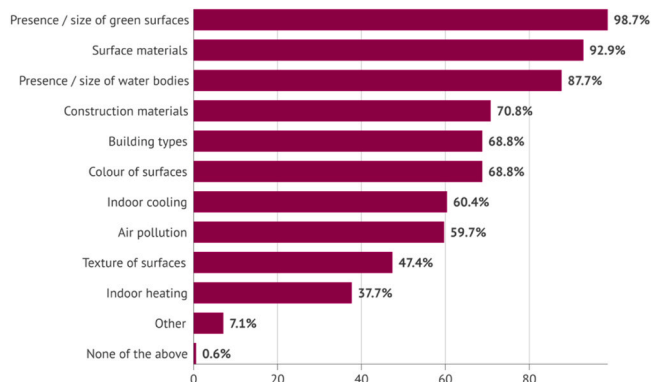
Gender distribution of survey respondents



Distribution of survey respondents' educational background

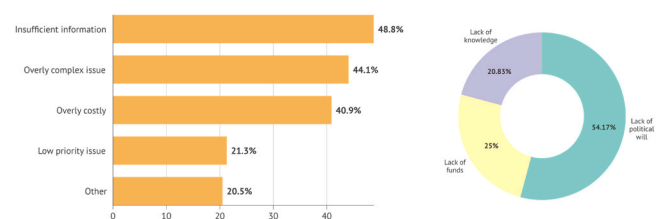


Distribution of survey respondents' borough of residence

Fig. 4. Demographics of online survey respondents ($n = 216$), showing distribution of their age, gender, educational background, and borough of residence.**Fig. 5.** Residents' perception of principal causes of UHI formation ($n = 216$).

Results from the online survey indicate that insufficient information is the main barrier to the implementation of green infrastructure, according to 48.8 % respondents, followed by it being an overly complex issue (44.1 %), or costly (40.9 %) (Fig. 6). According to interviewees from local governments, while residents generally support tree-planting projects, resistance to greening initiatives emerges when projects involve personal costs or disruptions to their daily lives.

Over 80 % of respondents indicated public acceptance of UHI

**Fig. 6.** Barriers to effective UHI mitigation as perceived by online survey respondents ($n = 216$).

mitigation projects is strongly linked to residents' understanding of the benefits, which in turn affects implementation rates. Nonetheless, survey results suggest limited public awareness of the purpose and functionality of hybrid infrastructure, despite a general perception of its effectiveness. Support or opposition is also influenced political alignment of those proposing and installing them. In Hungary's increasingly polarised landscape, policies are often judged based on the proposing party rather than their content, a phenomenon well documented by Cohen (2003). Such politicised responses undermine stable public support and present a challenge for evidence-informed policymaking.

A landscape architect noted persistent scepticism toward nature-based alternatives, which are often viewed as less reliable than technological fixes. Engineers, they argued, are perceived as 'trusted professionals that provide low-risk solutions, whereas landscape planners' work with the complexity of nature, which is usually taken with a grain of salt' – inviting doubt. However, this view contrasts with online survey results, whose respondents expressed a clear preference for nature-based over grey infrastructures (Fig. 7). Such divergences between expert perceptions and public attitudes highlight conflicting stakeholder preferences, posing a significant barrier to coherent UHI mitigation strategies.

Another barrier is the spatial constraints of a densely built urban fabric, compounded by soaring land prices and the influence of a powerful real estate lobby. Allocating space and public funds to projects that provide feasible outcomes that benefit local communities remains a challenge (Farina et al., 2024) – in the absence of formal valuation of ecosystem services (Cavender-Bares et al., 2022; van Adkins et al., 1997). For instance, the establishment of *Böszikert*, a 1500 m² community garden of 34 allotments in the 12th borough of Budapest in 2023 (Hegyvidéki Önkormányzat, 2023) was only feasible due to an economic downturn that left the land temporarily unused (Hegyvidéki Önkormányzat, 2023). The stalled construction industry – driven by rising energy costs and high interest rates amid a Eurozone recession (European Central Bank, 2022; Papunen, 2024) – opened a narrow window for non-commercial land use. Meanwhile, re-zoning of forestlands for residential development under increasing economic pressure is another example where short-term economic gains outweigh long-term public and environmental benefits (Magyar Kétfarkú Kutypárt, 2021). To counter such trends, Parvar et al. (2024) propose scenario-based urban growth modelling to guide planning decisions that prioritise climate mitigation infrastructure.

Further challenges to mitigating excess heat in Budapest include the

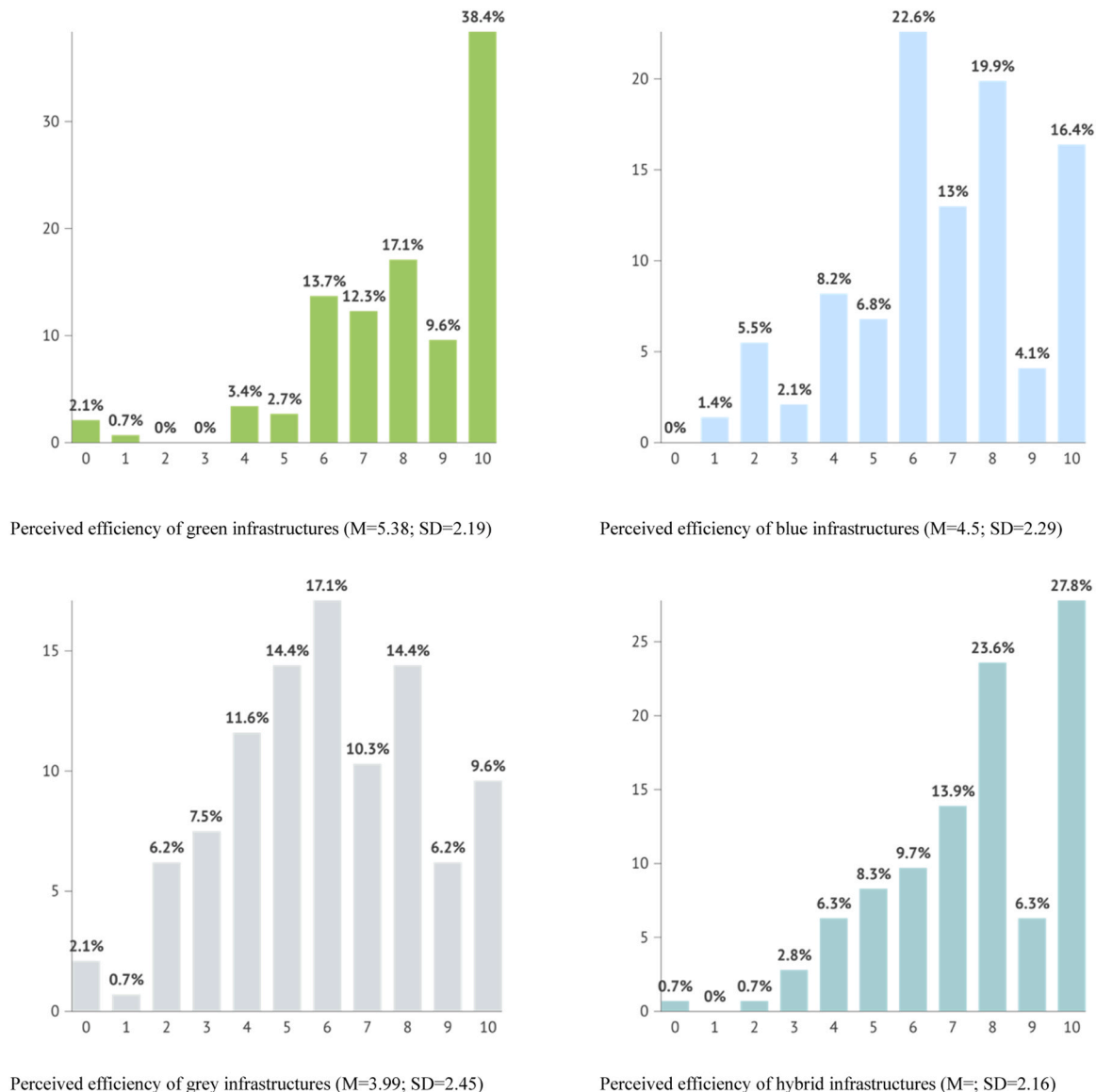


Fig. 7. UHI-mitigating efficacy of urban green, blue, grey, and hybrid infrastructures as perceived (on a 1–10 scale) by online survey respondents.

unclear distribution of responsibilities among governing bodies. Senior officials identified the double-tiered administration of Budapest – comprising the municipal government and 23 semi-autonomous boroughs – as a major obstacle to inter-governmental coordination and effective mitigation efforts. Additionally, ineffective communication is also a critical issue. Although the Budapest Climate Strategy outlines a

framework for intergovernmental cooperation (Tatai et al., 2021a, p. 8), the widespread consensus among interviewees that clearer responsibilities are necessary indicates that the current system is inadequate. Effective collaboration requires commitment from all parties. Yet, conflicting priorities – particularly at the national level – continue to hinder progress. A notable example is the abolition of the Ministry of

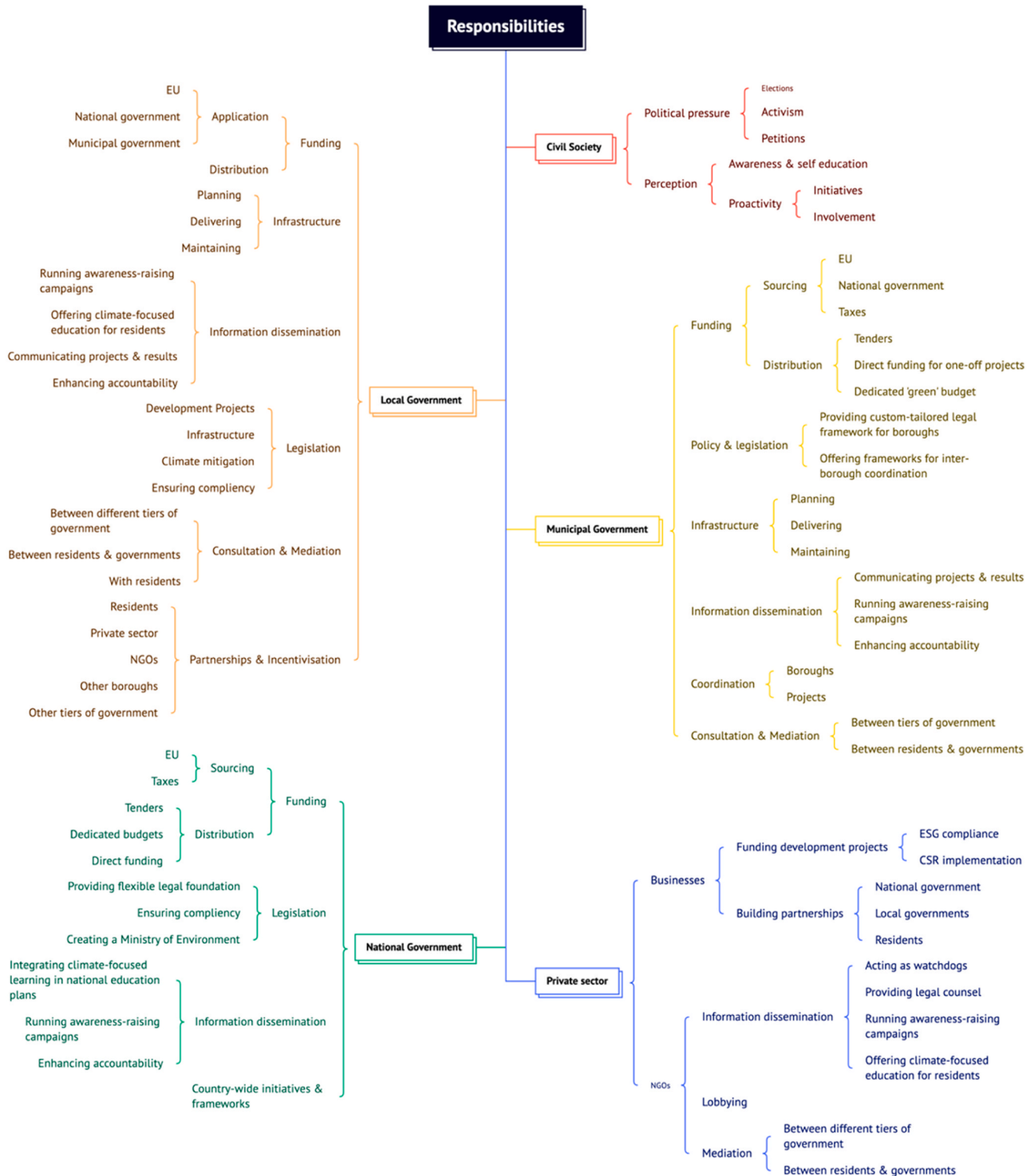


Fig. 8. Visual representation of the role of national, municipal, and local governments, civil society and the private sector in UHI-mitigation initiatives in Budapest, based on key informant interviews.

Environment and Water by the Second Orbán Government in 2010, clearly highlighting these divergent priorities (Rétvári, 2010). A further barrier is a limited understanding of how climate change impacts urban habitats, its effects on residents, and potential solutions, which contributes to lower public support for mitigation projects (Zhang et al., 2019). Given the political nature of urban planning projects, this lack of public backing is likely to impede implementation. Interviewees also emphasised the absence of science-informed action plans. For instance, street watering during heatwaves, an effective method to lower surface and ambient air temperatures on roads and tram tracks, is inconsistently applied across boroughs without standardised guidelines. While some boroughs are conducting in-situ experiments to develop evidence-based plans regarding temperature thresholds, optimal watering times, duration, and quantity – publicly available results are still pending as of September 2025 –, others follow more haphazard planning.

Many of these issues are recognised by the Budapest Climate Strategy (Tatai et al., 2021a), which, among others, acknowledges that professional organisations are not sufficiently involved in the decision-making processes; that there is insufficient central funding to encourage the public to save energy by retrofitting buildings; or that government measures often conflict with the interests of local authorities. Nonetheless, it is unclear what steps are to be taken to solve these issues.

3.4. What is the role of government, civil society, and private actors in UHI mitigation efforts?

Mitigating the UHI effect in Budapest requires cooperation between local, municipal, and national governments, as well as the private sector and civil society. Cooperation is predicated upon a thorough understanding of institutional hierarchies, underlying norms, values, and ideologies, as well as appropriate goal setting, compliance, and enforcement. The roles of diverse stakeholders in urban heat mitigation are summarised in a responsibility map (Fig. 8).

3.4.1. Government

Interview participants agreed that the national government's role in UHI mitigation should primarily be focused on providing financial resources, establishing a legal foundation to support localised regulatory frameworks, and disseminating accessible information through education and transparent communication. Survey results reflected similar views, with 89.2 % of participants favouring national government support through funding. Both interviewees and survey respondents stressed the need for improved climate education, with information dissemination ranked as a key responsibility for national (71.6 %) and local governments (80.4 %) alike. Municipal and local or borough-level governments were identified as best suited to driving climate action due to their closer ties to residents, better local knowledge, and simpler – thus more transparent – structures. Approximately 81.8 % of survey respondents favoured local government's roles in mediating between stakeholders, followed by providing information (80.4 %), proposing initiatives (79.7 %), and installing new infrastructure (74.3 %), as well as maintaining existing infrastructure (74.3 %). The municipal government is considered to have less access to funding than the national government. Although the municipal government is actively involved in organising public consultations; expanding public transport, developing cycling and pedestrian infrastructure; and funding buildings' energy efficiency improvements (e.g. installing solar panels), the ongoing demand for these efforts highlights an implementation gap.

3.4.2. Civil society

Interviewees and survey respondents often contrasted the bureaucratic functions of governments with the proactive role of citizens in proposing new projects (73 %) and maintaining infrastructure (56.3 %). Residents are expected to participate in voting, petitioning, and activism to influence government decisions and hold authorities accountable. Compliance with regulations is also crucial, as noted by respondents

from various government agencies. According to the Dezső Radó Plan (Tatai et al., 2021b), the municipal government oversees approximately 300,000 trees, the 23 borough governments manage roughly 700,000, and residents care for about two million. The overall condition of Budapest's urban green infrastructure is therefore significantly influenced by residents' efforts to maintain vegetation on private properties. Additionally, residents' energy consumption, transportation choices, and waste management habits impact UHI intensity, underscoring the importance of cooperation with government initiatives. Behavioural interventions – such as regulatory and economic nudges – are also considered effective for encouraging climate-friendly behaviours (Van der Heijden, 2019; Van der Heijden, 2014). Interviewees emphasised the need for awareness campaigns and information-sharing initiatives to enhance public understanding of UHI mitigation initiatives.

3.4.3. Private sector

Businesses and entrepreneurs were highlighted as key players in UHI mitigation through the integration of corporate social responsibility and environmental governance principles into their operations. Sustainable urban development initiatives not only address environmental challenges but can also provide competitive advantages for businesses. Public-private partnerships (PPPs) were identified as an underutilised opportunity to foster collaboration between private companies and local governments. These partnerships could channel funding into public projects, enhancing companies' reputation and increasing their appeal to socially conscious consumers and investors. Additionally, businesses could involve employees in team-building retreats, like tree planting and garden maintenance, with ethical credit systems rewarding such contributions.

4. Discussion

4.1. Factors that influence UHI and areas with significant UHI effect across the city

Empirical results provide a detailed understanding of the various factors that influence UHI intensity in Budapest, aligning closely with findings from global and local literature. The spatial patterns described by interview participants are confirmed by a cumulative heat map of average summer UHIs of Budapest, which reveals a peak temperature difference of 6°C between 2003 and 2020 (Fig. 9). The role of building insulation and surface material was highlighted in Gyulai's (2016)

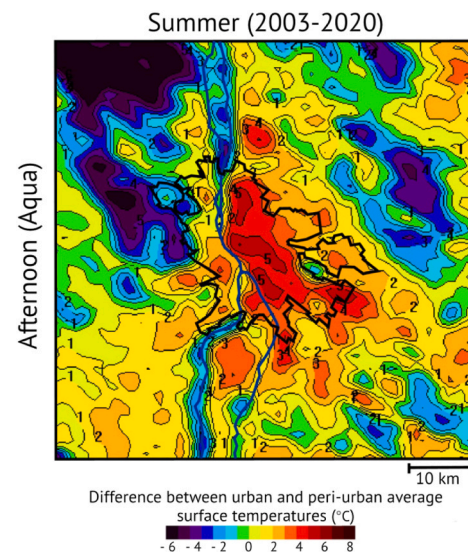


Fig. 9. Average summer UHI intensity in Budapest 2003–2020 (HungaroMet, 2024).

study, which demonstrated clear differences in façade temperatures between older and recently retrofitted buildings along the Danube on the Pest side. These findings underscore the importance of infrastructure upgrades – a priority strongly voiced by both interviewees and survey respondents.

Pongrácz, Dezső, and Bartholy (2022) surveyed UHI intensity during summer heatwaves in Budapest, highlighting the influence of surface materials, texture, and albedo on temperatures. Their findings confirm that concrete and asphalt are among the hottest materials, while rubber and painted wood also reach high temperatures, though less frequently mentioned by interviewees, possibly due to their limited presence in urban landscapes (e.g. paving for playgrounds, seat bars for public benches). Additionally, black, dark grey, red, and dark blue surfaces contribute most to elevated temperatures. These findings support participants' calls for reducing asphalt surfaces and increasing cool and green roofs, especially the prevalence of black (tar), grey (pebbledash), and red (terracotta tiles) in Budapest.

Gaál and Bukovszki (2022), from the Budapest-based research firm Advanced Building and Urban Design, stress the need to shift from conventional stormwater management – treating rain as surplus to be drained quickly – to approaches that value it as a resource. They advocate for hybrid infrastructures that enhance water retention, purification, and flood mitigation. Their findings highlight the need to replace impermeable materials with bioactive surfaces, echoing concerns raised by interviewees. Beyond surface properties, urban geometry and street orientation also influence heat dynamics. Mirabi and Davies (2024) emphasise the role of spatial configuration and cross-ventilation potential in mitigating UHI effects.

Finally, Probáld (2014) identifies interconnected climatic and non-climatic challenges in Budapest, including vegetation loss, adverse urban morphology, and intensive motorised transportation. In the absence of a flexible urban structure, the author highlights the need to capitalise on natural cooling zones, such as the Danube's banks, islands, and the Budai Hills (Probáld, 2014).

4.2. Effectiveness of UHI-mitigating infrastructures in Budapest

Results indicating the efficacy of green surfaces in mitigating UHIs align with findings of various studies. Abdulateef and Al-Alwan's (2022) report that green surfaces can be highly effective in UHI mitigation, with up to 21°C temperature differences in certain cases, averaging 11.7°C. Costanzo, Evola, and Marletta's (2016) analysis of green and cool roofs showed 20°C and 25°C temperature reductions, respectively. Moreover, Frickie et al.'s (2014) survey found an average of 8°C temperature difference between built-up and green areas within the 12th borough of Budapest, confirming data derived from key informant interviews. A series of studies (Dian et al., 2019; Incze et al., 2018; Pongrácz et al., 2017) shows that neighbourhood renovation projects have measurable impact on local UHI intensity, positively influencing residents' well-being. In a similar vein, the health-related influence of urban green infrastructures has recently been studied by Lungman et al. (2023), who found that *circa* 40 % of urban heat-related deaths in European cities could have been avoided if they had around 30 % grid-cell level tree coverage, underscoring the need for expanding green surfaces.

The surface area of green spaces was also found to be a key factor in Budapest. The Dezső Radó Plan aims to 'augment the current green surface per person within a 15-minute walking distance from 6 to 7 m² by 2030' (Tatai et al., 2021b, p. 26). Although this is still well below the 9 m² per person recommendation of the World Health Organisation (2017) and the European Environment Agency (2022), the Dezső Radó Plan notes that the additional 500 ha green surface that would be needed for the recommended target is not feasible in the current physical and legislative context of Budapest (Tatai et al., 2021b, p. 26). Alongside green space expansion, the Budapest Climate Strategy and the Dezső Radó Plan contend that appropriate maintenance is also crucial, for the vitality of vegetation greatly influences both its carbon

sequestration and evapotranspiratory capacities, which agrees with the interviewees' perspective. The vitality and maintenance needs of vegetation are, in turn, dependent upon the appropriate selection of plant species (Azmeer et al., 2024), which was also pointed out by an interviewee working on urban community garden projects.

Finally, an important factor influencing heat mitigation effectiveness is the heat-absorbing potential of water bodies. Although water bodies are generally found to be effective in reducing UHI intensity (Liu et al., 2021; Yang et al., 2016), several interview participants noted the Danube's limited mitigating potential, especially in summertime. Hathway and Sharples (2012) suggest this is likely to be caused by increased water temperatures that reduce the Danube's heat absorption potential. Szczuka, Báthoryné Nagy, and Lőrinczi's (2022) climate zone map of Budapest (see Fig. 2) also confirms the limited ability of the Danube to cool down its surroundings. Their study explores the influence of the geometry, location, density, composition, and condition of urban green infrastructure on the Danube's cooling capacity.

4.3. Barriers to installing and scaling UHI-mitigating infrastructures in Budapest

One of the principal barriers to effective UHI mitigation is the city's physical limitations. According to key informants affiliated with governmental organs and NGOs that work on tree planting projects, improving existing infrastructure (e.g. replacing or enriching poor soil quality) can be reasonably straightforward and relatively cost-effective. By contrast, gaining space for scaling existing solutions or installing new ones is significantly more challenging, since any significant expansion will require substantial alterations of the urban fabric, which is highly costly and challenging, both legally and logistically. Regulatory reform is therefore needed to support access to limited space and prioritise investing in heat mitigation infrastructure in combination with utilities to maximise infrastructure efficiency.

Non-physical barriers identified in this study can be broken down into two subcategories: inhibitive and obstructive. While inhibitive barriers (i.e. lack of awareness, priorities, political willingness, and limited acceptance of nature-based solutions) prevent action from being conceived or schemes from being launched, obstructive barriers (i.e. lack of funding, unfavourable legal frameworks, and bureaucratic environments) hinder ongoing projects and impede their efficiency. Some of the non-physical barriers identified by participants correspond to the enabling factors mentioned in Van der Heijden, 2019 paper on climate governance, which describes municipal and local governments' need for a supportive legal framework, autonomy, access to funding, vertical and horizontal coordination, learning networks, stakeholder engagement, and climate champions. In addition, the lack of context-specific strategies is also a significant non-physical barrier (Kearl and Vogel, 2023).

Another barrier evident from the survey and interviews is the disconnect between research and policymaking, often stemming from focus- and goal-misalignment (Kleerekoper, van Esch, and Salcedo, 2012). Although both the Budapest Climate Strategy and the Dezső Radó Plan draw on academic research, there is a range of topics that have been researched in-depth yet are scarcely featured in these documents. In the case of Budapest, this implementation gap is likely engendered by several interconnected factors: (1) the absence of city-wide policies and action plans for UHI mitigation; (2) the resulting voluntary nature of mitigation projects; (3) the complexity of the two-tier governing system that obscures responsibility structures; (4) insufficient coordination between the city, its boroughs, as well as among individual boroughs; (5) and the unequal financial capacities across boroughs. As a result, the performance of local governments in mitigating UHIs varies significantly. To understand why only some of the available pertinent expert information ends up being used, a rigorous investigation of information flows between stakeholders is needed to improve evidence-informed guidelines for restructuring the city.

4.4. The role of government, civil society, and private actors in UHI mitigation efforts

Climate governance is a complex regime whose workings depend on an elaborate system of cooperation between different levels of governments and stakeholders. It is predicated upon a thorough understanding of institutional hierarchies, underlying norms, values, and ideologies, as well as appropriate goal setting, compliance, and their enforcement. Similar to prior research (C40 and ARUP, 2017; City of Sydney, 2019; Green Commission, 2013; NYC Mayor's Office of Sustainability, 2018; Simpson et al., 2010), interviewees and survey respondents consistently highlighted the limited direct involvement of the national government, alongside an unwillingness to cooperate and unfulfilled responsibilities in improving climate resilience. They expressed a clear preference for municipal and borough-level governments to take the lead in climate resilience projects. This aligns with the findings of several studies. Reckien et al. (2014) found that cities often demonstrate higher climate governance ambitions than their corresponding states, positioning them as key catalysts for progressive climate action. Van der Heijden (2014, 2019) draws attention to an emergent approach that critiques state-led regulatory interventions while advocating for bottom-up collaborations involving citizens, businesses, and local governments. Lee and Painter (2015) advocate for researchers and NGOs also to be included in developing comprehensive climate policies. And, similarly, Tatai et al. (2022) highlight the need to update national legislation and management of urban green infrastructure, although their analysis falls short of identifying other responsibilities that were noted by interviewees, such as providing funding or disseminating up-to-date information.

For instance, some boroughs implement a range of initiatives, such as distributing plants, compost bins, and rainwater collection vessels; running awareness-raising campaigns and education programmes; conducting building surveys; and experimenting with UHI techniques. Conversely, other boroughs lack delineated climate agendas altogether. And even when UHI mitigation is addressed, it often serves as a complementary effort to, rather than a core component of, urban governance (Van der Heijden, 2019; Van der Heijden, 2014).

Another persistent challenge is the aforementioned ambiguity of goal- and target-setting (Hofstad et al., 2021). This is exemplified by Budapest's commitment to various international frameworks – including the Covenant of Mayors, the Compact of Mayors (now unified under the Covenant of Mayors for Climate and Energy), the Under 2 Coalition, and the C40 Cities' Clean Construction Declaration – which involve broad commitments but often lack clearly defined implementation pathways. In addition to issues of tokenism, some initiatives have also been criticised for their neoliberal and technocratic approach, which ultimately perpetuates business as usual (Wolfram et al., 2019).

Various researchers (Jodoin et al., 2015; Jordan et al., 2015; Malm, 2021; Tosun and Schoenefeld, 2017; Zhang et al., 2019) argue that collective action and greater inclusion of local stakeholders – civilians, climate initiatives, grassroots organisations – in decision-making fosters more effective, inclusive, and equitable outcomes. Highlighting that climate challenges are not solely technical, but also fundamentally distributional in nature, they emphasise the need for addressing structural inequalities. In addition to the diversity of perspectives, the framing of deliberative processes is also important, for it 'informs the diagnosis of the problem, the selection of legitimate viewpoints, the definition of alternatives, as well as the prescriptions for how the problem should be addressed' (Blue, 2015, p. 3).

A notable example of inclusive climate governance is the first Budapest Climate Meeting in 2020, organised by the Municipal Assembly of Budapest as a follow-up to its Climate Emergency Declaration in 2019 (Fővárosi Közgyűlés, 2019), which mirrored a similar declaration by the European Parliament (2019). Over two days of consultations, participants formulated 21 proposals outlining what Budapest should aim to achieve in addressing the climate crisis and how these goals might be realised (Bart et al., 2020). Although still falling short of true

'citizen control' (Arnstein, 1969), this is the first known city-level decision-making process, where a government-in-charge went beyond merely providing education or offering tokenistic consultations to form meaningful partnerships with its citizens.

In addition to citizens and NGOs, bringing in the private sector helps to drive infrastructure projects by providing funding, technology, skills and knowledge and increased efficiency. This would help mitigate economic constraints, which were identified by interview participants and survey respondents alike as core reasons for the lack of UHI-related infrastructure development, even amidst favourable policy environments. Historically, the main reasons for the limited presence of PPPs in Hungary have been a lack of supportive cultural context and the unwillingness of governments to partake in financial risk distribution (Kozma, 2013, 2016). While public opinion seems to have become more supportive of PPPs, such partnerships continue to be underutilised.

In their analysis of PPP involvement in urban development in Slovenia, Bugaric et al. (2019) describe a situation comparable to Hungary's, where barriers to PPP formation include such systemic obstacles as inadequate policies, historic public mistrust in PPPs, inefficiencies in municipal administration, and a lack of expertise within local governments. They argue that overcoming these challenges requires a more goal-oriented approach, stronger administrative support, and, importantly, centralised best-practice sharing initiatives through advisory bodies to showcase successful PPP models. Their recommendation concurs with the findings of other similar studies (Eriguchi et al., 2024; He et al., 2019). They also suggest that more transparent allocation of EU funds – which in Hungary has been mired in corruption (Greiling, 2022; Kállay, 2015; Ligeti et al., 2024) – would encourage greater private sector participation. Finally, stronger financial incentives, including higher investment returns than standard bank interest rates, along with 'de-risking' mechanisms, are also necessary to attract private investors (Taylor and Harman, 2016).

5. Conclusions

This paper empirically explores both various factors that give rise to and intensify the UHI effect in Budapest and the benefits of green, blue, grey, and hybrid infrastructures in adapting and mitigating urban heat, in accordance with targets of the 11th Sustainable Development Goals (SDGs; sustainable cities and communities) (United Nations, 2015). In addition, broader involvement of diverse stakeholders in climate action working directly towards SDG 13 (climate action). Hybrid solutions offer great potential in terms of their high public acceptability and numerous co-benefits, such as ameliorating physical and mental well-being, in line with SDG 3's commitment of good health and well-being, along with SDGs 6 (clean water and sanitation), 7 (access to affordable energy), and 15 (life on land) (SDG, 2015). Strategically planned hybrid infrastructure can maximise the efficacy of its components, while reducing cost and increasing compatibility with the characteristics of specific locations and existing infrastructure.

Four key findings can be elicited from this study. First, the principal issue around the UHI phenomenon in Budapest seems not to be decision-makers' lack of understanding of the factors that influence its intensity, but the absence of targeted policy actions taken to reduce the UHI effect. Second, grey and hybrid solutions receive inadequate attention, which indirectly limits the efficacy of UHI mitigation efforts. Third, a shortage of space and a lack of regulatory and legislative support are major factors that hinder UHI mitigation. Finally, there is a pervasive implementation gap, coupled with the lack of accountability, which gives rise to doubts regarding governmental dedication to tackling UHI formation.

Various future avenues for research hold potential. First, a Budapest-based survey of the Danube is needed to better understand the limits of its cooling capacity, influencing factors and ways in which it could be enhanced or utilised. Second, Budapest-focused research specifically examining the efficacy of hybrid infrastructures in UHI mitigation needs to be conducted. Third, futures studies should include economic

feasibility and cost-effectiveness assessments, including a comprehensive survey of Budapest's building stock, such as insulation quality, roof structures and geometries, surface materials, piping and heating systems. Fourth, to improve the understanding of communication issues between stakeholders, a thorough investigation of information flows is needed. Finally, updates of the Budapest Climate Strategy are needed, for instance, to include more details of the influence of surface materials on albedo, the advantages of green walls and roofs, and building materials and urban heat. To support this, an accessible monitoring system to support the strategy's implementation is needed.

While the study site's distinctive characteristics – such as its geographic setting, regulatory and legal frameworks, and climate governance models – may limit direct transferability, the paper's findings on barrier recognition and responsibility structures provide valuable insights for researchers and practitioners seeking to identify hybrid infrastructure opportunities for improved mitigation efficiency. We hope these findings will inform and inspire future research and policy-making on urban heat, not only in Budapest, but in other high-density Central European cities and comparable contexts elsewhere.

CRediT authorship contribution statement

Jessica P R Thorn: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Agoston M Horanyi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

Our paper is not under review by any other journal, and the research has undergone relevant ethical approvals. We have no declarations of interest.

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Appendix 1. . Questionnaire for semi-structured key informant interviews

- (1) What is your occupation?
- (2) What is your age?
- (3) What gender do you identify with?
- (4) How long have you been living in Budapest?
- (5) In what context (when, where, and how) did you first hear/learn about urban heat islands?
- (6) How and where did you find information on UHIs?
- (7) What do you think are the primary causes of UHIs in general?
- (8) What factors influence the UHIs' effect in Budapest? (e.g. surface area, reflective properties, wind speeds, pollution levels, evaporation, runoff, etc.)
- (9) Where is UHIs effect most significant across the city?
- (10) How do you think UHIs should be tackled in Budapest?
- (11) What is the effectiveness of green, blue, grey, and hybrid infrastructure for mitigating urban heat in general?

- (12) What is the effectiveness and viability of green, blue, grey, and hybrid infrastructure for mitigating urban heat in Budapest?
- (13) Are there any barriers to the scaling of these solutions in Budapest?
- (14) How could they be overcome?
- (15) In sum, what are the most effective ways of mitigating urban heat effects in Budapest?
- (16) Who are or should be responsible for driving change?
- (17) Who should be involved in mitigation efforts?
- (18) What is the role of local and national governments in mitigation efforts?
- (19) What is the role of the national government in mitigation efforts?
- (20) What is the role of the public in mitigation efforts?
- (21) What is the role of private actors in mitigation efforts?
- (22) What is the degree of public acceptability of installing and maintaining green and blue spaces and grey and hybrid infrastructures in Budapest?

Appendix 2. : Online survey

- (1) Age range (multiple choice)
- (2) Gender (multiple choice)
- (3) District of residence (multiple choice)
- (4) Length of residency (text entry)
- (5) Highest level of education (multiple choice)
- (6) Occupation (text entry)
- (7) Have you ever heard about the UHI effect? (multiple choice)
- (8) How much would you say you know about the phenomenon? (Likert scale)
- (9) In your view, what is the relative risk severity of UHIs compared to other climate change-related risks? (Likert scale)
- (10) What do you think, how well does Budapest manage UHI? (Likert scale)
- (11) What are the issues with the way Budapest approaches UHIs? (multiple choice)
- (12) What factors do you think impact UHIs? (multiple choice)
- (13) Have you actively sought out information on UHIs? (multiple choice)
- (14) Have you thought about doing something to tackle UHI-related issues? (multiple choice)
- (15) If yes, what? (text entry)
- (16) Have you ever engaged with relevant projects? (choice)
- (17) If yes, how? (text entry)
- (18) Who do you think is responsible for mitigation initiatives? (multiple choice)
- (19) Who should be involved in mitigation efforts? (multiple choice)
- (20) What is the role of local governments? (multiple choice)
- (21) What is the role of the national government? (multiple choice)
- (22) What is the role of ordinary citizens? (multiple choice)
- (23) Do you know anyone whose life or health has been impacted by heat waves? (multiple choice)
- (24) Have you ever experienced a heatwave (multiple choice)?
- (25) If yes, how severely did it affect you? (Likert scale)
- (26) If yes, what impact did it have on you? (multiple choice)
- (27) Do you know anyone who has been affected by heat waves? (multiple choice)
- (28) Did you know about it beforehand? (multiple choice)
- (29) If yes, where did you hear about it? (multiple choice)
- (30) If yes, did you prepare against its effects? (multiple choice)
- (31) If yes, how? (multiple choice)
- (32) If not, why? (multiple choice)
- (33) Once the heat wave hit, did you do anything to lessen its effect? (multiple choice)
- (34) If yes, what? (multiple choice)
- (35) If not, why? (multiple choice)
- (36) When did the heatwave(s) occur? (multiple choice)

- (37) Do you support the creation/expansion of green spaces in Budapest? (multiple choice)
- (38) If yes, what types would you prefer? (multiple choice)
- (39) If no, why? (multiple choice)
- (40) How effective do you think green spaces are in mitigating urban heat? (Likert scale)
- (41) Do you currently have a garden of any size or type / belong to community gardens of any type? (multiple choice)
- (42) If yes, specify (multiple choice)
- (43) If no, would you consider creating/joining one? (multiple choice)
- (44) If no, why? (multiple choice)
- (45) Would you support making green spaces (green balcony, green roof, etc.) mandatory? (multiple choice)
- (46) If no, why? (multiple choice)
- (47) Do you support the creation or expansion of blue infrastructure in Budapest? (multiple choice)
- (48) If yes, what types would you prefer? (multiple choice)
- (49) If no, why? (multiple choice)
- (50) How effective do you think blue infrastructure is in mitigating urban heat? (Likert scale)
- (51) Would you support mandating the improvement and expansion of blue infrastructure in your neighbourhood? (multiple choice)
- (52) If no, why? (multiple choice)
- (53) Would you support the expansion of UHI mitigating grey infrastructure in Budapest? (multiple choice)
- (54) If yes, what types would you prefer? (multiple choice)
- (55) If no, why? (multiple choice)
- (56) How effective do you think grey infrastructure is in mitigating urban heat? (Likert scale)
- (57) Does the building where you live currently have any of the following? (multiple choice)
- (58) Does the neighbourhood where you live have any of the following? (multiple choice)
- (59) If no, would you like to have them created and/or installed? (multiple choice)
- (60) If no, why? (multiple choice)
- (61) Would you support making the adoption of UHI-mitigating grey infrastructure mandatory? (multiple choice)
- (62) If no, why? (multiple choice)
- (63) Would you support the expansion and/or installation of UHI mitigating hybrid infrastructure in Budapest? (multiple choice)
- (64) If yes, what types would you prefer? (multiple choice)
- (65) If no, why? (multiple choice)
- (66) How effective do you think hybrid infrastructure is in mitigating UHIs? (Likert scale)
- (67) Does the neighbourhood where you live have any of the following? (multiple choice)
- (68) If no, would you like to have them created and/or installed? (multiple choice)
- (69) If no, why? (multiple choice)
- (70) Would you support making the adoption of UHI-mitigating hybrid infrastructure mandatory? (multiple choice)
- (71) If no, why? (multiple choice)

References

- Abdulateef, M.F., Al-Alwan, H.A.S., 2022. The effectiveness of urban Green infrastructure in reducing surface urban heat island. *Ain Shams Eng. J.* 13, 101526. <https://doi.org/10.1016/j.asej.2021.06.012>.
- Almaaitah, T., Appleby, M., Rosenblat, H., Drake, J., Joksimovic, D., 2021. The potential of blue-Green infrastructure as a climate change adaptation strategy: a systematic literature review. *BlueGreen. Syst.* 3, 223–248. <https://doi.org/10.2166/bgs.2021.016>.
- Apritasari, Y.D., Indraprastha, A., Wonorahardjo, S., 2024. The role of building mass configuration and material selection for mitigating the intensity of the urban heat island. *Energy Build.* 323, 114822. <https://doi.org/10.1016/j.enbuild.2024.114822>.
- Arnfield, A.J., 2003. Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. *Int. J. Clim.* 23, 1–26. <https://doi.org/10.1002/joc.859>.
- Arnstein, S.R., 1969. A ladder of citizen participation. *J. Am. Inst. Plann.* 35, 216–224. <https://doi.org/10.1080/01944366908977225>.
- Azmeer, A., Tahir, F., Al-Ghamdi, S.G., 2024. Progress on Green infrastructure for urban cooling: evaluating techniques, design strategies, and benefits. *Urban Clim.* 56, 102077. <https://doi.org/10.1016/j.uclim.2024.102077>.
- Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R.F., Pegenaute, F., Herrmann, F.R., Robine, J.M., Basagaña, X., Tonne, C., Antó, J.M., Achebak, H., 2023. Heat-related mortality in Europe during the summer of 2022. *Nat. Med.* 29, 1857–1866. <https://doi.org/10.1038/s41591-023-02419-z>.
- Bart, I., Bartos, K., Bördös, É., Fodor, M., Hennig, B., Miklós, Z., Németh, D., 2020. Klímaváltozástól van, mit tegyen Budapest? Jelentés a 2020 Budapesti Közösségi Gyűlésről [What should Budapest do in the face of climate emergency? Report on the 2020 Budapest Community Meeting]. Budapest Közösségi Gyűlés, Budapest.
- Blue, G., 2015. Public participation and climate governance: Opening up or closing down policy options (Working Paper), Public Participation and Climate Governance Working Paper Series. University of Calgary.
- Bodnár, Z., 2023. Minden rekord megdőlt, 2023 júliusa lesz a valaha mért legmelegebb hónap [All records broken, July 2023 will be the hottest month ever]. Qubit.
- Bohnenstengel, S.I., Hamilton, I., Davies, M., Belcher, S.E., 2014. Impact of anthropogenic heat emissions on London's temperatures: impact of anthropogenic heat emissions. *Q. J. R. Meteorol. Soc.* 140, 687–698. <https://doi.org/10.1002/qj.2144>.
- Bronstert, A., 2003. Floods and climate change: interactions and impacts. *Risk Anal.* 23, 545–557. <https://doi.org/10.1111/1539-6924.00335>.
- Bugaric, B., Fikfak, A., Nikšić, M., Mujčić, S., Konjar, M., Grom, J.P., Koritnik, B., Blaganje, M., Pirnat, R., Plicanic, S., 2019. Public-private partnerships for urban development: stakeholder views in Slovenia. *Eur. Public Law* 25, 325–345. <https://doi.org/10.5464/EURO2019020>.
- Buzási, A., 2022. Comparative assessment of heatwave vulnerability factors for the districts of Budapest, Hungary. *Urban Clim.* 42, 101127. <https://doi.org/10.1016/j.uclim.2022.101127>.
- C40, A.R.U.P., 2017. Deadline 2020—How cities will get the job done. (https://www.c40.org/wp-content/uploads/2021/07/Deadline_2020.pdf) (access 13.12.24).
- Callaghan, M., Schlusner, C.-F., Nath, S., Lejeune, Q., Knutson, T.R., Reichstein, M., Hansen, G., Theokritoff, E., Andrijevic, M., Brecha, R.J., Hegarty, M., Jones, C., Lee, K., Lucas, A., Van Maanen, N., Menke, I., Pfeiderer, P., Yesil, B., Minx, J.C., 2021. Machine-learning-based evidence and attribution mapping of 100,000 climate impact studies. *Nat. Clim. Change* 11, 966–972. <https://doi.org/10.1038/s41558-021-01168-6>.
- Cavender-Bares, J.M., Nelson, E., Meireles, J.E., Lasky, J.R., Miteva, D.A., Nowak, D.J., Pearse, W.D., Helmus, M.R., Zanne, A.E., Fagan, W.F., Mihai, C., Muller, N.Z., Kraft, N.J.B., Polasky, S., 2022. The hidden value of trees: quantifying the ecosystem services of tree lineages and their major threats across the contiguous US. *Sustain. Transform.* 1 (4), 1–26. <https://doi.org/10.1371/journal.pstr.0000010>.
- City of Sydney, 2019. Sustainable Sydney 2030, Community Strategic Plan 2017–2021. City of Sydney, Sydney.
- Cohen, G.L., 2003. Party over policy: the dominating impact of group influence on political beliefs. *J. Pers. Soc. Psychol.* 85, 808–822. <https://doi.org/10.1037/0022-3514.85.5.808>.
- Copernicus Climate Change Service, 2023. July 2023 sees multiple global temperature records broken. (<https://climate.copernicus.eu/july-2023-sees-multiple-global-temperature-records-broken>) (access 10.12.24).
- Costanzo, V., Evola, G., Marletta, L., 2016. Energy savings in buildings or UHI mitigation? Comparison between Green roofs and cool roofs. *Energy Build.* 114, 247–255. <https://doi.org/10.1016/j.enbuild.2015.04.053>.
- Csóka, G., 2023. 25-ször több hőség is lehet Budapesten a század végére, kritikus fontosságú a zöldfelületek óvása és kiterjesztése [Budapest could experience 25 times more heatwaves by the end of the century, protecting and expanding green spaces is critical]. Máfélők. URL (<https://masfeloek.hu/2023/07/18/hosegnap-hohullam-budapest-klimavaltozas-varosi-hoszigit-zoldfeluletek-fak/>) (accessed 8.7.23).
- de Linares, P.G., Filepné Kovács, K., Iváncsik, V., Máté, K., Valánszki, I., 2018. Green governance in metropolitan regions. *Corvinus Reg. Stud.* 3, 79–100.
- Degirmenci, K., Desouza, K.C., Fieuw, W., Watson, R.T., Yigitcanlar, T., 2021. Understanding policy and technology responses in mitigating urban heat islands: a literature review and directions for future research. *Sustain. Cities Soc.* 70, 102873. <https://doi.org/10.1016/j.scs.2021.102873>.
- Deilami, K., Kamruzzaman, Md, Liu, Y., 2018. Urban heat island effect: a systematic review of spatio-temporal factors, data, methods, and mitigation measures. *Int. J. Appl. Earth Obs. Geoinf.* 67, 30–42. <https://doi.org/10.1016/j.jag.2017.12.009>.
- Dezső, Z., Pongrácz, R., Bartholy, J., 2022. Surface urban heat island characteristics in Budapest (Hungary) during the summer period (other). *European Meteorological Society*. <https://doi.org/10.5194/ems2022-515>.
- Dian, C., Pongrácz, R., Dezső, Z., Bartholy, J., 2020. Annual and monthly analysis of surface urban heat island intensity with respect to the local climate zones in Budapest. *Urban Clim.* 31, 100573. <https://doi.org/10.1016/j.uclim.2019.100573>.
- Dian, C., Pongrácz, R., Incze, D., Bartholy, J., Talamon, A., 2019. Analysis of the urban heat island intensity based on air temperature measurements in a renovated part of Budapest (Hungary). *Geogr. Pannonica* 23, 277–288. <https://doi.org/10.5937/gp23-23839>.
- Doick, K.J., Peace, A., Hutchings, T.R., 2014. The role of one large greenspace in mitigating London's nocturnal urban heat island. *Sci. Total Environ.* 493, 662–671. <https://doi.org/10.1016/j.scitotenv.2014.06.048>.

- ECMWF, 2023. Urban heat islands and heat mortality: Demonstrating heat stress in European cities. European Centre for Medium-Range Weather Forecasts, Reading. (<https://stories.ecmwf.int/urban-heat-islands-and-heat-mortality>) (access 3.1.25).
- Erighuchi, J., Murnane, E., Murray, B., Noble, T., 2024. Bangkok Cooling Initiative: Incentivizing Private Investment for Urban Heat Mitigation in Bangkok, Thailand. (<https://www.pp.u-tokyo.ac.jp/wp-content/uploads/2016/02/20240129-Group-8-Final-Paper-Bangkok-Cooling-Initiative.pdf>) (access 11.11.24).
- European Central Bank, 2022. The impact of the war in Ukraine on euro area energy markets. Econ. Bull. 4. (https://www.ecb.europa.eu/press/economic-bulletin/fo-cus/2022/html/ecb.ebbbox202204_01~68ef3c3dc6.en.html) (access 12.1.25).
- European Environment Agency, 2022. Who benefits from nature in cities? social inequalities in access to urban green and blue spaces across Europe. (No. 15/2021). European Environment Agency, Copenhagen. (<https://www.eea.europa.eu/en/analysis/publications/who-benefits-from-nature-in-cities-social-inequalities-in-access-to-urban-green-and-blue-spaces-across-europe>) (access 23.10.24).
- European Parliament, 2019. The European Parliament declares climate emergency [WWW Document]. News Eur. Parliam. URL (<https://www.europarl.europa.eu/news/en/press-room/20191121IPR67110/the-european-parliament-declares-climate-emergency>) (accessed 7.29.23).
- Farina, G., Neverre, N., Hérivaux, C., Barriere, J., Pinson, S., Habarou, H., Perea, J.-C., Le Coënt, P., 2024. How to account for spatial trade-offs in planning for urban climate adaptation? Optimizing Green and grey infrastructures. J. Environ. Manag. 372, 123380. <https://doi.org/10.1016/j.jenvman.2024.123380>.
- Farkas, J.Z., Kovács, Z., Csomós, G., 2022. The availability of Green spaces for different socio-economic groups in cities: a case study of Budapest. Hung. J. Maps 18, 97–105. <https://doi.org/10.1080/17445647.2022.207943>.
- Ferdowsi, A., Piadeh, F., Behzadian, K., Mousavi, S.-F., Ehteram, M., 2024. Urban water infrastructure: a critical review on climate change impacts and adaptation strategies. Urban Clim. 58, 102132. <https://doi.org/10.1016/j.uclim.2024.102132>.
- Fővárosi Közgyűlés, 2019. Budapest Főváros Önkormányzata Közgyűlésének rendeletei [Decrees of the General Assembly of the Municipality of Budapest]. F. öv. áros. K. özlöNy. 79, 1982–2012.
- Frickle, C., Pongrácz, R., Dezső, Z., Bartholy, J., 2014. A vegetáció szerepe a budapesti városi hősziget jelenségben [Impacts of Vegetation on Urban Heat Island of Budapest]. Légkör. Atmosphere 59, 150–153. (<http://real.mtak.hu/id/eprint/29006>).
- Gaál, A., Bukovszki, V., 2022. Nature-based Solutions III: Even unpredictable rain is worth a fortune, Nature-based Solutions. Advanced Building and Urban Design, Budapest.
- Giyasova, I., 2021. Factors affecting microclimatic conditions in urban environment. E3S Web Conf. 244. <https://doi.org/10.1051/e3sconf/202124406010>.
- Göndöcs, J., Breuer, H., Pongrácz, R., Bartholy, J., 2017. Urban heat island mesoscale modelling study for the Budapest agglomeration area using the WRF model. Urban Clim. 21, 66–86. <https://doi.org/10.1016/j.uclim.2017.05.005>.
- Green Commission, 2013. Building a green city. City of Amsterdam, Amsterdam.
- Greiling, G., 2022. EU-Funding – A key area of corruption in Hungary. Quo Vademus. (<https://quo-vademus.eu/eu-funding-a-key-area-of-corruption-in-hungary/>) (access 5.9.24).
- Gyulai, M.G., 2016. Budapesti városi hősziget-hatás termovíziós vizsgálata [Thermovisual study of the urban heat island effect in Budapest]. Budapesti Műszaki és Gazdaságtudományi Egyetem [Budapest University of Technology and Economics], Budapest.
- Hathway, E.A., Sharples, S., 2012. The interaction of rivers and urban form in mitigating the urban heat island effect: a UK case study. Build. Environ. 58, 14–22. <https://doi.org/10.1016/j.buildenv.2012.06.013>.
- Han, R., Marchant, R.A., Thorn, J.P.R., 2024. Global disparities in wellbeing from Green infrastructure cooling services: a systematic review. Urban For. Urban Green. 97, 128372. <https://doi.org/10.1016/j.ufug.2024.128372>.
- Han, R., Marchant, R.A., Thorn, J.P.R., 2025. Are vulnerable neighbourhoods left behind? Urban cooling disparities from greenspace inequality in Antananarivo, Madagascar. Urban Clim. 61, 102467. <https://doi.org/10.1016/j.uclim.2025.102467>.
- He, B.-J., Zhu, J., Zhao, D.-X., Gou, Z.-H., Qi, J.-D., Wang, J., 2019. Co-benefits approach: opportunities for implementing sponge city and urban heat island mitigation. Land Use Policy 86, 147–157. <https://doi.org/10.1016/j.landusepol.2019.05.003>.
- He, M., Yuan, C., Zhang, X., Wang, P., Yao, C., 2023. Impacts of Green-blue-grey infrastructures on high-density urban thermal environment at multiple spatial scales: a case study in wuhan. Urban Clim. 52, 101714. <https://doi.org/10.1016/j.uclim.2023.101714>.
- He, X.-F., Jiang, W.-M., Chen, Y., Liu, G., 2007. Numerical simulation of the impacts of anthropogenic heat on the structure of the urban boundary layer. Chin. J. Geophys. 50, 75–83. <https://doi.org/10.1002/cjg2.1012>.
- Hegyvidéki Önkormányzat [Local Government of Hegyvidék], 2023. Közösséggé érlelődött a Bőszikert [Bőszikert Matured into a Community Garden].
- Hofstad, H., Millstein, M., Tønnesen, A., Vedeld, T., Hansen, K.B., 2021. The role of goal-setting in urban climate governance. Earth Syst. Gov. 7, 100088. <https://doi.org/10.1016/j.esg.2020.100088>.
- HungaroMet, 2024. HuClim data set. (https://odp.met.hu/climate/homogenized_data/gridded_data_series/) (access 15.11.24).
- Ince, D., Pongrácz, R., Dezső, Z., Bartholy, J., 2018. A városi hősziget hatás napi menetének összehasonlító elemzése budapesti helyszíni mérések alapján [Comparational analysis of the urban heat island effect using in-situ measurements in Budapest]. F. öltudományok és K. önyezet. Harmóniában. [Earth Sci. Environ. Harmon. J. Magy. F. öltani Társulat [Geol. Soc. Hung.] Pécs 119–122.
- IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35–115. <https://doi.org/10.59327/IPCC/AR6-9789291691647>.
- Iungman, T., Cirach, M., Marando, F., Pereira Barboza, E., Khomenko, S., Masselot, P., Quijal-Zamorano, M., Mueller, N., Gasparrini, A., Urquiza, J., Heris, M., Thondoo, M., Nieuwenhuijsen, M., 2023. Cooling cities through urban Green infrastructure: a health impact assessment of european cities. Lancet 401, 577–589. [https://doi.org/10.1016/S0140-6736\(22\)02585-5](https://doi.org/10.1016/S0140-6736(22)02585-5).
- Jodoin, S., Duyck, S., Lofts, K., 2015. Public participation and climate governance: an introduction. Rev. Eur. Comp. Int. Environ. Law 24, 117–122. <https://doi.org/10.1111/reel.12126>.
- Jordan, A.J., Huitema, D., Hildén, M., Van Asselt, H., Rayner, T.J., Schoenefeld, J.J., Tosun, J., Forster, J., Boasson, E.L., 2015. Emergence of polycentric climate governance and its future prospects. Nat. Clim. Change 5, 977–982. <https://doi.org/10.1038/nclimate2725>.
- Kállay, L., 2015. The Corruption Risks of EU Funds in Hungary (No. 978-615-80267-0-0). Transparency International, Budapest. (<https://transparency.hu/wp-content/uploads/2015/11/TheCorruptionRisksOfEUfunds.pdf>) (access 1.11.24).
- Kearl, Z., Vogel, J., 2023. Urban extreme heat, climate change, and saving lives: lessons from Washington state. Urban Clim. 47, 101392. <https://doi.org/10.1016/j.uclim.2022.101392>.
- Khor, N., Arimah, B., Otieno Otieno, R., van Oostrum, M., Mutinda, M., Oginga Martins, J., 2022. World cities report 2022: Envisaging the future of cities (No. HS/004/22E). UN Habitat, Nairobi, Kenya.
- Kleerekoper, L., van Esch, M., Salcedo, T.B., 2012. How to make a city climate-proof, addressing the urban heat island effect. Resour. Conserv. Recycl. 64, 30–38. <https://doi.org/10.1016/j.resconrec.2011.06.004>.
- Kotharkar, R., Surawar, M., 2016. Land use, land cover, and population density impact on the formation of canopy urban heat islands through traverse survey in the nagpur urban area, India. J. Urban Plan. Dev. 142, 04015003. [https://doi.org/10.1061/\(ASCE\)UP.1943-5444.0000277](https://doi.org/10.1061/(ASCE)UP.1943-5444.0000277).
- Kovács, Z., Farkas, Z.J., Egedy, T., Kondor, A.C., Szabó, B., Lennert, J., Baka, D., Kohán, B., 2019. Urban sprawl and land conversion in post-socialist cities: the case of metropolitan Budapest. Cities 92, 71–81. <https://doi.org/10.1016/j.cities.2019.03.018>.
- Kozma, M., 2016. A Public-Private partnership Magyarországon – Miért nem működik, és hogyan működhetne? PublicPriv. Partnersh. Hung. Why do they Not. Work how could they?]. Vezetud. Bp. Manag. Rev. 19–32. <https://doi.org/10.14267/VEZTUD.2016.02.03>.
- Kozma, M., 2013. A public-private partnership Magyarországon – egy félreértés volt? [Public-private partnerships in Hungary – was it a mistake? Vezetud. Bp. Manag. Rev. 20–27. <https://doi.org/10.14267/VEZTUD.2013.02.02>.
- KSH, 2023a. Magyarország és Budapest időjárásának adatai [Weather data for Hungary and Budapest]. (https://www.ksh.hu/stadat_files/kor/hu/kor0037.html) (access 2.2.24).
- KSH, 2023b. A lakónépesség nem, vármegye és régió szerint (2023. január 1.) [Population by sex, county, and region (1st of January 2023)]. (https://www.ksh.hu/stadat_files/nep/hu/nep0034.html) (access 2.2.24).
- Landsberg, H.E., 1981. The urban climate. In: Int. Geophys. Ser., 28. Academic press, New York.
- Lee, T., Painter, M., 2015. Comprehensive local climate policy: the role of urban governance. Urban Clim. 14, 566–577. <https://doi.org/10.1016/j.uclim.2015.09.003>.
- Li, H., Wang, G., Jombach, S., 2020. Characteristics of winter urban heat island in Budapest at local and micro scale. J. Environ. Geogr. 13, 34–43. <https://doi.org/10.2478/jengeo-2020-0010>.
- Li, Z., Liu, Q., Yan, K., Xiong, D., Xu, P., Yan, Y., Lin, L., 2024. Cooling effects of urban parks under various ecological factors. Urban Clim. 58, 102134. <https://doi.org/10.1016/j.uclim.2024.102134>.
- Liang, Z., Huang, J., Wang, Y., Wei, F., Wu, S., Jiang, H., Zhang, X., Li, S., 2021. The mediating effect of air pollution in the impacts of urban form on nighttime urban heat island intensity. Sustain. Cities Soc. 74, 102985. <https://doi.org/10.1016/j.scs.2021.102985>.
- Ligeti, M., Martin, J.P., Tilistyk, A., Zeisler, J., Zegnál, J., 2024. Corruption Perceptions Index and Hungary's track record of corruption, 2023. Transparency International Hungary. (https://transparency.hu/wp-content/uploads/2024/01/CPI_2023_report_EN.pdf) (access 10.8.25).
- Liu, Z., Cheng, W., Jim, C.Y., Morakinyo, T.E., Shi, Y., Ng, E., 2021. Heat mitigation benefits of urban Green and blue infrastructures: a systematic review of modeling techniques, validation and scenario simulation in ENVI-met V4. Build. Environ. 200, 107939. <https://doi.org/10.1016/j.buildenv.2021.107939>.
- Magyar Kétfarkú Kutypárt, 2021. Jó hír! Még több kockaház és lakópark építhető az új építési szabályzatnak köszönhetően. [Good news! Even more block houses and apartment complexes can be built thanks to the new building code.] Kétfarkú Kutypárt. URL (<https://ketfarkukutya.mkkp.party/2020/11/25/eszak-hegyvideki-kesz-valtozasok/>) (accessed 1.12.25).
- Major, A., 2021. Milliárdnyi klíma terheli a bolygót [Billions of ACs polluting the planet]. Greendex.
- Malm, A., 2021. How to blow up a pipeline: learning to fight in a world on fire, First edition paperback, ed. Verso, London.
- Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Pidcock, R., Chen, Y., Lonnoy, E., Moufouma-Okia, W., Connors, S., Zhou, X., Maycock, T., Tignor, M., Péan, C., Matthews, J.B.R., Gomis, M.L., Waterfield, T., 2018. Global warming of 1.5°C. IPCC, Incheon. (https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf) (access 21.8.25).

- Mirabi, E., Davies, P.J., 2024. Mitigating urban heat along roadways; systematic review of impact and practicability. *Urban Clim.* 58, 102207. <https://doi.org/10.1016/j.uclim.2024.102207>.
- Mokhtari, Z., Barghjelveh, S., Sayahnia, R., Karami, P., Qureshi, S., Russo, A., 2022. Spatial pattern of the Green heat sink using patch- and network-based analysis: implications for urban temperature alleviation. *Sustain. Cities Soc.* 83, 103964. <https://doi.org/10.1016/j.scs.2022.103964>.
- Moreno, E., Arimah, B., Otieno Otieno, R., Mbeche-Smith, U., Klen-Amin, A., Kamiya, M., 2016. World cities report 2016: Urbanization and Development — Emerging Futures. UN Habitat, Nairobi, Kenya.
- Mudu, P., Adair-Rohani, H., deSouza, P., Gumy, S., de Sá, T.H., Lewis, J., Mwaura, A., Shairsingh, K., Vert, C., Williams, K., Smit, W., Owusu, G., Wrigley-Asante, C., Agyei-Mensah, S., 2023. Tracking urban health policies: a conceptual framework with special focus on air pollution in African cities. WHO, Geneva.
- Mumtaz, M., 2024. Green infrastructure as key tool for climate adaptation planning and policies to mitigate climate change: evidence from a Pakistani city. *Urban Clim.* 56, 102074. <https://doi.org/10.1016/j.uclim.2024.102074>.
- Musco, F. (Ed.), 2016. Counteracting Urban Heat Island Effects in a Global Climate Change Scenario, 2016th ed. Springer International Publishing, Cham. <https://doi.org/10.1007/978-3-319-10425-6>.
- Nerem, R.S., Beckley, B.D., Fasullo, J.T., Hamlington, B.D., Masters, D., Mitchum, G.T., 2018. Climate-change-driven accelerated sea-level rise detected in the altimeter era. *Proc. Natl. Acad. Sci.* 115, 2022–2025. <https://doi.org/10.1073/pnas.1717312115>.
- Nguyen, T.T., Ngo, H.H., Guo, W., Wang, X.C., Ren, N., Li, G., Ding, J., Liang, H., 2019. Implementation of a specific urban water management - sponge city. *Sci. Total Environ.* 652, 147–162. <https://doi.org/10.1016/j.scitotenv.2018.10.168>.
- NYC Mayor's Office of Sustainability, 2018. Aligning New York City with the Paris Climate Agreement. New York: City of New York. City of New York, New York, NY.
- Ogashawara, I., Bastos, V., 2012. A quantitative approach for analyzing the relationship between urban heat islands and land cover. *Remote Sens* 4, 3596–3618. <https://doi.org/10.3390/rs4113596>.
- Oke, T.R., 1988. Street design and urban canopy layer climate. *Energy Build.* 11, 103–113. [https://doi.org/10.1016/0378-7788\(88\)90026-6](https://doi.org/10.1016/0378-7788(88)90026-6).
- Oke, T.R., 1983. City size and the urban heat island, 1967. *Atmos. Environ.* 7, 769–779. [https://doi.org/10.1016/0004-6981\(73\)90140-6](https://doi.org/10.1016/0004-6981(73)90140-6).
- Oke, T.R., 1982. The energetic basis of the urban heat island. *Q. J. R. Meteorol. Soc.* 108, 1–24. <https://doi.org/10.1002/qj.49710845502>.
- Oke, T.R., 1981. Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations. *J. Clim.* 1, 237–254. <https://doi.org/10.1002/joc.3370010304>.
- Oke, T.R., 1978. Boundary layer climates. Routledge, London.
- Oláh, A.B., 2012. The possibilities of decreasing the urban heat island. *Appl. Ecol. Environ. Res.* 10, 173–183. https://doi.org/10.15666/aer/1002_173183.
- Papunen, A., 2024. Economic impact of Russia's war on Ukraine: European Council response.
- Parker, C., Scott, S., Geddes, A., 2019. Snowball Sampling. Sage Research Methods Foundations. London, SAGE Publications Ltd.
- Parvar, Z., Mohammadzadeh, M., Saeidi, S., 2024. Enhancing decision-making for climate change mitigation and sustainable urban growth. *Urban Clim.* 58, 102223. <https://doi.org/10.1016/j.uclim.2024.102223>.
- Pine, J., Aves, K., Funk, K., Zuhayr, A., Kocis, K., 2023. Urban heat Island Effect Solutions and Funding. National League of Cities, Washington, DC.
- Pongrácz, R., Bartholy, J., Dezső, Z., Dian, C., 2016. Analysis of the air temperature and relative humidity measurements in Budapest-Ferencváros. *Hung. Geogr. Bull.* 65, 93–103. <https://doi.org/10.15201/hungeobull.65.2.1>.
- Pongrácz, R., Dezső, Z., Bartholy, J., 2022. Analysing the urban heat island of Budapest during summer heat waves. (<https://pannex.org/wp-content/uploads/2022/11/Analysing-the-urban-heat-island.pdf>) (access 18.7.24).
- Pongrácz, R., Dian, C., Incze, D., Máté, K., Dezső, Z., Bartholy, J., 2017. Budapest városklimatológiai helyszíni mérések elemzése [Analysis of In-Situ Urban Climatological Measurements in Budapest]. *Légekör. Atmosphere* 61, 126–129.
- Pongrácz, R., 2021. Ettől válnak forró katlanok városaink: a hősziget hatás [This is what makes our cities hot: the heat island effect]. Másfél fok. URL (<https://masfelfok.hu/2021/07/27/ettol-valnak-forro-katlanok-varosaink-a-hosziget-hatas/>) (accessed 8.7.23).
- Pörtner, H.-O., Tignor, M., Alegria, A., Löschke, S., Poloczanska, E., Craig, M., Möller, V., Roberts, D., Mintenbeck, K., Langsdorf, S., Bardhy, R., 2023. Climate Change 2022: Impacts, Adaptation and Vulnerability. IPCC, Geneva, Switzerland. (https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FrontMatter.pdf).
- Probáld, F., 2014. The urban climate of Budapest: past, present and future. *Hung. Geogr. Bull.* 63, 69–79. <https://doi.org/10.15201/hungeobull.63.1.6>.
- Probáld, F., 1974. Budapest városklimája [The Urban Climate of Budapest]. Akadémiai Kiadó, Budapest.
- Rajagopalan, P., Lim, K.C., Jamei, E., 2014. Urban heat island and wind flow characteristics of a tropical city. *Sol. Energy* 107, 159–170. <https://doi.org/10.1016/j.solener.2014.05.042>.
- Reckien, D., Flacke, J., Dawson, R.J., Heidrich, O., Olazabal, M., Foley, A., Hamann, J.J.-P., Orru, H., Salvia, M., De Gregorio Hurtado, S., Geneletti, D., Pietrapertosa, F., 2014. Climate change response in Europe: what's the reality? Analysis of adaptation and mitigation plans from 200 urban areas in 11 countries. *Clim. Change* 122, 331–340. <https://doi.org/10.1007/s10584-013-0989-8>.
- Rétvári, B., 2010. 2010. évi XLII. törvény a Magyar Köztársaság minisztériumainak felsorolásáról [Act XLII of 2010 concerning the List of Ministries of the Republic of Hungary].
- Révész, A., 2008. Stochastic behaviour of heat waves and temperatures in Hungary. *Appl. Ecol. Environ. Res.* 6, 85–100. https://doi.org/10.15666/aer/0604_085100.
- Rosenzweig, C., Solecki, W.D., Romero-Lankao, P., Mehrotra, S., Dhakal, S., Ali Ibrahim, S. (Eds.), 2018. Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network, 1st ed. Cambridge University Press. <https://doi.org/10.1017/9781316563878>.
- Sailor, D.J., 2011. A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment: estimating anthropogenic heat and moisture emissions. *Int. J. Clim.* 31, 189–199. <https://doi.org/10.1002/joc.2106>.
- Shahmohamadi, P., Che-Ani, A.I., Maulud, K.N.A., Tawil, N.M., Abdullah, N.A.G., 2011. The impact of anthropogenic heat on formation of urban heat island and energy consumption balance. *Urban Stud. Res.* 2011, 1–9. <https://doi.org/10.1155/2011/497524>.
- Simpson, R., Arian, Y., Nüsse, A., Schuthof, R., Tusinski, O., Otto-Zimmermann, K., Pérez Sueiro, V., 2010. Cities in a Post-2012 Climate Policy Framework. ICLEI, Bonn.
- Szczuka, L., Báthoryné Nagy, I.R., Lőrinczi, R., 2022. Budapest lokális klímazóna-térképe – LCZ BP. 4D Táj. építészeti ÉS. Kertműv. észeti F. 28–43. <https://doi.org/10.36249/62.3>.
- Taha, H., Akbari, H., Rosenfeld, A., Huang, J., 1988. Residential cooling loads and the urban heat island—the effects of albedo. *Build. Environ.* 23, 271–283. [https://doi.org/10.1016/0360-1323\(88\)90033-9](https://doi.org/10.1016/0360-1323(88)90033-9).
- Tatai, Z., Bódi-Nagy, A., Orosz, I., Becsák, P., Pető, Z., Szabó, K., 2021a. Budapesti Klímastratégia és Fenntartható Energia- és Klíma Akcióterv [Budapest Climate Strategy and Sustainable Energy and Climate Action Plan].
- Tatai, Z., Szóke, B., Niedetzky, A., Terem, V., Szilágyi, K., Báthoryné Nagy, I.R., Bedőcs, B., Gábor, P., 2021b. Radó Dezső Terv: Budapest Zöldinfrastruktúra Fejlesztési és Fenntartási Akcióterve [Dezső Radó Plan: the Budapest Green Infrastructure Development and Maintenance Action Plan].
- Tatai, Z., Zétényi, D., Niedetzky, A., Bódi-Nagy, A., Frits, B., Szabó, Katalin, Orosz, I., Szabó, Krisztián, Becsák, P., 2022. Budapest környezeti állapotértékelése 2022 [Budapest Environmental Assessment 2022]. Fővárosi Önkormányzat, Budapest.
- Taylor, B.M., Harman, B.P., 2016. Governing urban development for climate risk: what role for public-private partnerships? *Environ. Plan. C. Gov. Policy* 34, 927–944. <https://doi.org/10.1177/0263774X15614692>.
- TessaDEM, 2024. Budapest Topographic Map.
- Tong, S., Prior, J., McGregor, G., Shi, X., Kinney, P., 2021. Urban heat: an increasing threat to global health. *BMJ*. <https://doi.org/10.1136/bmj.n2467>.
- Tosun, J., Schoenefeld, J.J., 2017. Collective climate action and networked climate governance. *WIREs Clim. Change* 8. <https://doi.org/10.1002/wcc.440>.
- Ucal, M., Xydís, G., 2020. Multidirectional relationship between energy resources, climate changes and sustainable development: technoeconomic analysis. *Sustain. Cities Soc.* 60, 102210. <https://doi.org/10.1016/j.scs.2020.102210>.
- United Nations, 2015. Transforming our world: The 2030 Agenda for Sustainable Development (A/RES/70/1). United Nations General Assembly. (<https://sdgs.un.org/2030agenda>) (access 15.7.25).
- United States Environmental Protection Agency, 2012. Reducing Urban Heat Islands: Compendium of Strategies. U.S. Environmental Protection Agency, Washington, DC.
- Ute, A., István, A., Krisztina, L., Béla, N., Péter, S., János, K., Gábor, K., András, R., Zsombor, T., Aurél, P., Andrea, N., Dávid, Z., Zoltán, P., Mihály, L., Péter, R., László, P., István, O., 2013. Budapest 2030: Hosszútávú Városfejlesztési Konceptió [Budapest 2030: Long-term Urban Development Plan]. Budapest Főváros Főpolgármesteri Hivatal, Budapest.
- van Adkins, R.C., Kuhns, M.R., Blahna, D.J., Blood, M.W., 1997. Urban forest resource management at hill air force base, ogden, utah. *J. Arboric.* 23.
- Van der Heijden, J., 2014. Governance for urban sustainability and resilience: Responding to climate change and the relevance of the built environment. Edward Elgar Publishing. <https://doi.org/10.4337/9781782548133>.
- Van der Heijden, J., 2019. Studying urban climate governance: where to begin, what to look for, and how to make a meaningful contribution to scholarship and practice. *Earth Syst. Gov.* 1, 100005. <https://doi.org/10.1016/j.esg.2019.100005>.
- Verstraete, M.M., Brink, A.B., Scholes, R.J., Beniston, M., Stafford Smith, M., 2008. Climate change and desertification: where do we stand, where should we go? *Glob. Planet. Change* 64, 105–110. <https://doi.org/10.1016/j.gloplacha.2008.09.003>.
- Wang, X., Li, H., Sodoudi, S., 2022. The effectiveness of cool and Green roofs in mitigating urban heat island and improving human thermal comfort. *Build. Environ.* 217, 109082. <https://doi.org/10.1016/j.buildenv.2022.109082>.
- WHO, 2017. Urban Green Spaces: a brief for action. World Health Organization, Copenhagen. (<https://iris.who.int/bitstream/handle/10665/344116/9789289052498-eng.pdf?sequence=1>) (access 12.7.24).
- Wolfram, M., Van Der Heijden, J., Juhola, S., Patterson, J., 2019. Learning in urban climate governance: concepts, key issues and challenges. *J. Environ. Policy Plan* 21, 1–15. <https://doi.org/10.1080/1523908X.2018.1558848>.
- Xu, H., Sheng, K., Gao, J., 2023. Mitigation of heat island effect by Green stormwater infrastructure: a comparative study between two diverse Green spaces in nanjing. *Front. Ecol. Evol.* 11, 1307756. <https://doi.org/10.3389/fevo.2023.1307756>.
- Yang, L., Qian, F., Song, D.-X., Zheng, K.-J., 2016. Research on urban heat-island effect. *Procedia Eng.* 169, 11–18. <https://doi.org/10.1016/j.proeng.2016.10.002>.
- Zhang, L., Fukuda, H., Liu, Z., 2019. Households' willingness to pay for Green roof for mitigating heat island effects in Beijing (China). *Build. Environ.* 150, 13–20. <https://doi.org/10.1016/j.buildenv.2018.12.048>.