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Stakeholder analysis on the current situation and possible integration of Nature-based Solutions in Zurich and investigation of cooling efficiency and improvement of outdoor thermal conditions with Nature-based Solutions in Novi Sad.

Bachelor Thesis

by

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Abstract

Resource depletion, climate change, and ecosystem degradation are challenges facing cities worldwide and will increase if cities do not adapt. To address these challenges, we need to take a holistic approach to transform our cities into sustainable systems. One element to achieve this transition is the implementation of nature-based solutions (NBS). NBS can provide a range of ecosystem services that are beneficial to cities, such as microclimate regulation, flood prevention, water purification, food provisioning, and more.

To ensure the successful implementation of NBS and to identify the enabling conditions and barriers to NBS in Zurich, three groups of stakeholders were identified: (i) academics, (ii) governments, and (iii) NGOs. Semi-structured interviews with representatives of these three groups were conducted in Zurich, Switzerland. The interviews were transcribed and coded using Amberscript. To facilitate the use of NBS in Zurich, the main barriers to the implementation of NBS were identified from those mostly mentioned. The following main barriers were identified: (i) lack of resources, (ii) lack of knowledge, (iii) improper design, (iv) lack of communication, (v) lack of teamwork, (vi) lack of space, (vii) lengthy bureaucracy and (viii) lack of protected areas.

The interviews showed, that for increasing the use of NBS in Zurich, a review of existing laws, bureaucracy, well thought and sustainable planning, providing information on NBS, and education about NBS. For the implementation, it depends on the agreement and cooperation of all experts, professionals, politicians, and the population. Communicating must not be lacking.

Additionally, to show an example of the cooling efficiency of NBS in cities, micrometeorological measurements were performed in different urban spaces (grey urban areas, with and without trees and an urban park with and without trees) in Novi Sad, Serbia, on a hot summer day on 17 August 2022. Air temperature, relative humidity, wind speed, and globe temperature were measured, while Mean Radiant Temperature (T_{mrt}), and Physiologically Equivalent Temperature (PET) were calculated for each location.

Results showed that urban areas are the most uncomfortable areas in terms of T_a, T_g, T_{mrt} and PET. Relative Humidity is the highest in the urban park and the lowest in the urban areas. Furthermore, shading mostly from trees in a park has a great positive impact on the improvement of outdoor thermal comfort (OTC) conditions and provides a cooling effect for the local population during hot summer days.

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Introduction

Even though the urban environment occupies only 2% of the earth's surface, it uses around 80% of the world's energy and produces 75% of global CO_2 emissions. Furthermore, material consumption has increased eightfold in the last 100 years and will increase three times more (Koop & van Leeuwen, 201a7; Krausmann et al., 2009; UNEP, 2011). This is expected to lead to the increasing shortage of resources such as fertile land including nutrients, clean water and air, and raw materials like metals, wood, and plastics (Ellen Macarthur Foundation, 2015). This puts pressure on rural areas and the rural ecosystem to maintain water, energy, and food supplies and to dispose of waste safely.

Despite technological innovations and improved public awareness of environmental impacts, the increase in urbanisation will make the goal of a 50% reduction in CO_2 emissions by 2050 very difficult (R. Davies, 2021). In addition, today's food, energy, and water systems, while making technological advances, are not achieving sufficient results in addressing global challenges due to inadequate communication and cross-sectoral collaboration. The challenge of urban resilience cannot be solved by a single sector or discipline. Municipalities and politicians need to find a way to meet these requirements and therefore it seems crucial to invest in interdisciplinary solutions that address urban metabolism as a whole and expand the boundaries of the urban biosphere (Dong et al., 2016; Fujii et al., 2016; Kennedy et al., 2009).

The concept of circular economy (CE) proposes to replace the current linear flow of resources ending in waste disposal by closing the loop through reduction, reuse, and recycling of resources in a given system. The European Commission has adopted an ambitious CE package that promotes measures that contribute to "closing the loop" of product life cycles through recycling and reuse, which brings significant environmental and economic benefits (EU, 2022).

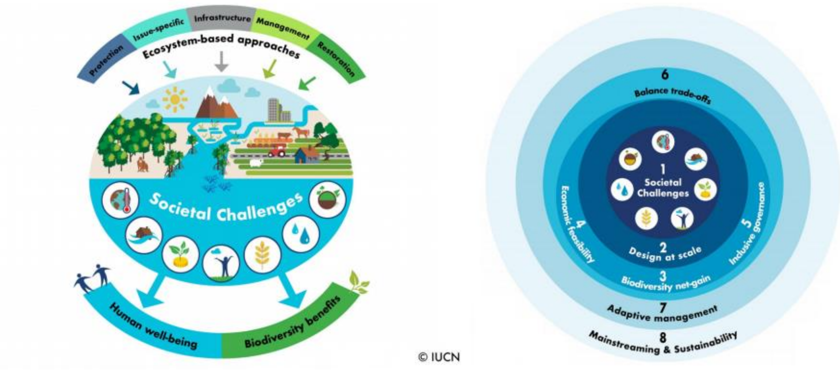
In the 2000s, the concept and the term Nature-based Solutions (NBS) emerged in environments science and conservation and has been in focus since, because of its high potential to address several urban challenges such as climate mitigation, air quality, water management, participatory planning, and governance (Raymond et al., 2017). International organisations such as the IUCN and the World Bank sought solutions that work with ecosystems rather than relying on conventional engineering measures (Cohen-Shacham et al., 2016). NBS goes beyond the traditional principles of biodiversity conservation and management by placing people at the centre of the debate and incorporating societal factors such as human well-being and poverty alleviation, socio-economic development, and governance principles (Eggermont et al., 2015). NBS can be closely linked to ideas such as agriculture in natural systems, natural solutions, ecosystem-based approaches, green infrastructures, and ecological engineering (Borsje et al., 2011; Canzonieri, 2007; Cowan et al., n.d.; Dudley et al., 2009; Schönborn & Junge, 2021; Sonneveld et al., 2018).

However, there is still a significant lack of consensus in the conceptualisation of NBS, especially in terms of typologies, nomenclature, and performance assessments related to ecosystem services (ES) and urban challenges (UC) (Castellar et al., 2021a).

The International Union for Conservation of Nature (IUCN) and the European Commission have developed their own definitions of NBS, which are broadly similar but with some key differences. The IUCN definition emphasises that a well-managed or restored ecosystem must be at the heart of any NBS, while the European Commission's definition is broader and places more emphasis on applying solutions that not only use nature but are also inspired and supported by nature (*Table 1*).

The European Union COST (Cooperation in Science and Technology) Action Circular City is an interdisciplinary research network that brings researchers and innovators together (COST, 2021). This includes city planners, architects, system designers, circular economists, engineers, and researchers from the social and natural sciences who can connect to develop systems for the CE in cities. They address challenges such as resource depletion, climate change, and ecosystem degradation and work to transform cities into sustainable systems using a holistic approach. One element to achieve this transition is the implementation of NBS, which also have their own definition (*Table 1*). The concept of linking urban challenges with NBS was developed in the COST Action CA17133 Circular City, which explored the hypothesis that a circular system, such as NBS used to manage nutrients and resources in the urban biosphere, leads to a resilient, sustainable and healthy urban environment (Langergraber et al., 2020).

Table 1: IUCN's, the European Commission's, and COST Action definitions of NBS

IUCN definition	*"Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."* (IUCN, 2020) *(Figure 1).*  *Figure 1: Illustration of Nature-based Solution (UN environment programme & Schweizerische Eidgenossenschaft, 2021)*
European Commission definition	*"Living solutions that are inspired by, continuously supported by and use nature to address various societal challenges in a resource-efficient and adaptive way, while providing economic, social and environmental benefits."* (Maes & Jacobs, 2017)
COST Action definition	*"NBS are defined as concepts that bring nature into cities and those that are derived from nature. NBS address societal challenges and enable resource recovery, climate mitigation and adaptation challenges, human well-being, ecosystem restoration and/or improved biodiversity status, within the urban ecosystems. As such, within this definition we achieve resource recovery using organisms (e.g. microbes, algae, plants, insects, and worms) as the principal agents. However, physical and chemical processes can be included for recovery of resources, as they may be needed for supporting and enhancing the performance of NBS."* (Langergraber et al., 2020)

Castellar et al., 2021b condensed the findings from four European projects to pave the way for a common understanding of NBS and thus facilitate their mainstreaming. The discussions of experts of the COST network resulted in a list of 32 NBS (*Table 2*).

Table 2: NBS common list and terminology (Castellar et al., 2021b).

Acronym	**Name**	**Acronym**	**Name**
NBS 1	Infiltration basin	NBS 17	Large urban park
NBS 2	(Wet) Retention Pond	NBS 18	Pocket garden/park
NBS 3	Rain garden	NBS 19	Urban forest
NBS 4	Swale	NBS 20	Heritage garden
NBS 5	Constructed wetland	NBS 21	Private garden
NBS 6	Green façade	NBS 22	Community garden
NBS 7	Green wall system	NBS 23	Urban Orchard
NBS 8	Vertical mobile garden	NBS 24	Use of pre-existing vegetation
NBS 9	Planter green wall	NBS 25	Composting
NBS 10	Vegetated pergola	NBS 26	Soil improvement
NBS 11	Extensive green roof	NBS 27	Systems for erosion control
NBS 12	Intensive green roof	NBS 28	Riverbank engineering
NBS 13	Semi-intensive green roof	NBS 29	Rivers or streams, including re-meandering, re-opening Blue corridors
NBS 14	Create and preserve habitats and shelters for biodiversity	NBS 30	Reprofiling/Extending floodplain area
NBS 15	Street trees	NBS 31	Diverting and deflecting elements
NBS 16	Green corridors	NBS 32	Vegetated grid pave

2. Chapter 1: Stakeholder analysis of the current situation and possible integration of Nature-based Solutions in Zurich

2.1 Introduction

The concept of NBS has recently come into focus as it offers great potential to address various urban challenges such as climate change mitigation, air quality, water management, participatory planning, and governance (Raymond et al., 2017). One of the most appreciated features of NBS is its co-benefits and multifunctionality. Although designed for a specific purpose (e.g. urban drainage), NBS can provide multiple ecosystem services at the same time (e.g. treatment, evaporative cooling and, energy savings). A single element can serve as insulation for a building and a wastewater treatment plant at the same time (Chung et al., 2021; Connop et al., 2016; Cruz et al., 2021; Lane et al., 2015). Circular cities need to cope with two major challenges, firstly the conservation of natural resources by reducing their import and secondly the minimisation of waste production by using resources in cycles (Atanasova et al 2021). Both challenges are general in nature and need to be specified for different resource flows (water, food, materials, and energy). The following urban circular challenges (UCC) for moving to a CE can be addressed with NBS:

- Restoration and conservation of the water cycle (through rainwater management).
- Water and waste treatment, recovery, and reuse
- Nutrient recovery and reuse
- Material recovery and reuse
- Food and biomass production
- Energy efficiency and energy recovery
- Building systems recovery

For the successful implementation of NBS, a high level of social acceptance is a basic requirement (Huijts et al., 2012). To achieve this, it is necessary to understand the obstacles, challenges and, support for the realisation of NBS in an urban area (Nesshöver et al., 2017). Several studies have analysed the barriers and enablers of NBS using stakeholder analysis (Balzan et al., 2022; L. Li et al., 2020; O'Donnell et al., 2017; Zingraff-Hamed et al., 2020). In most case studies, political, institutional, financial, and biophysical knowledge-related barriers have been identified as the major barriers to NBS (Faivre et al., 2017; L. Li et al., 2020; Lorenzoni et al., 2007; Sarabi et al., 2020; Urban GreenUp, 2019, p. 5). This may be a lack of awareness and understanding of NBS approaches and, the crucial role of nature in adaptation (entrenched attitudes and norms), a lack of accessible finance, and flawed approaches to economic valuation leading to underinvestment in NBS. In addition, many of the benefits of NBS are difficult to monetise and there is limited knowledge and evidence to justify the economic benefits of their use (especially when compared to 'business-as-usual' alternatives). Not to mention inflexible and highly sectoral policy and regulatory frameworks, existing direct and indirect subsidies, and governance issues that continue to favour grey, engineered solutions. Technical challenges and capacity gaps also prevent wider implementation (Kapos et al., 2019; Seddon et al., 2020). Furthermore, there are only a few case studies that have analysed several cities in the EU (Faivre et al., 2017). Therefore, in the framework of COST Action 17133 "Circular Cities", a comparative study of the factors influencing urban planning and urban governance policies was carried out in several European cities from North to South and from East to West to better understand the use of NBS in urban planning.

The information was provided by interviewing the main stakeholders who stated their experiences and expertise on NBS. This analysis was conducted in the cities of Reykjavik (Iceland), Ljubljana (Slovenia), Cordoba (Spain), Budapest (Hungary), Vienna (Austria) and, Zurich (Switzerland) (*Table 3*).

Table 3: Which interviews were conducted in 2022 for the stakeholder analysis and their basic information (quantity of population, area, geographical location and, features.

Cities	**Reykjavik (Iceland)**	**Ljubljana (Slovenia)**	**Cordoba (Spain)**	**Budapest (Hungary)**	**Vienna (Austria)**	**Zurich (Switzerland)**
Population	135'688 (2022)	284'293 (2022)	450'000 (2022)	3'100'000 (2020)	1'900'000 (2022)	421'878 (2020)
Area (km^2)	273	163.8	1'253	525.2	414.6	91.9
Location	Southwest of the island at the foot of the Rekjanesskagi peninsula.	In central Slovenia, between the Alps and the Karst.	In the north centre of the Autonomous Region of Andalusia.	At the centre of the Carpathian Basin.	In north-eastern Austria, at the easternmost extension of the Alps in Vienna Basin.	On the northern end of lake Zurich.
Latitude	64.128288	46.056946	37.89155	47.49835	48.20849	47.36667
Longitude	-21.827774	-14.505751	-4.77275	19.04045	16.37208	8.55
Features	The oldest and largest city in Iceland. A typical Nordic city, with developed industrial traditions and the production of all the basic things. Known as being the world's "Greenest City" for its use of hydro and geothermal power.	Capital of Slovenia In 2016, it won the award of the European Green Capital.	The capital of the province of Andalusia. The Guadalquivir River flows through the province from east to west, halfway between its source and its mouth, watering a fertile cultivation area where grain, wine, and olive trees grow.	The city is the political, administrative, industrial, and commercial centre of Hungary. The city lies on the Danube in a natural landscape where the hills of western Hungary meet the plains stretching to the east and south.	Vienna, the capital of Austria. Of the nine federal states, Vienna is the smallest in terms of area, but the largest in terms of population. Vienne took first place in the ranking of "The World's 10 Greenest Cities 2020" and was also voted "Most Liveable City".	More in the next pages
Sources	(Briney, 2018; Statistics Iceland, 2022; Writer, 2022)	(City of Ljubjana, 2016; City Population, 2022)	(Geodatos, 2022b; Harvard University & NBER, 2022; Junta de Andalucía & EU, 2011)	(Eurostat, 2022; Geodatos, 2022a; László, 2022)	(Geodatos, 2022c; Holzner et al., 2022; Mohr, 2022; Österreich Werbung, 2020)	(Geodatos, 2022d; Stadt Zürich Präsidialdepartement, 2022; statista, 2021)

This paper presents the current situation and the possible integration of NBS in Zurich. The study area was the city of Zurich, which is in the northeastern part of Switzerland (47.3769 N, 8.5417 E). It has a total area of 91.9 km², of which 21.8 % is forest, 12.1 % is a building area, 13.9 % is road, and 5.6 % is water (Stadt Zürich, 2022e).

Switzerland is a federal state in which cantons and municipalities have a great deal of leeway in implementing their NBS. Voters can sign a popular initiative or launch one themselves to demand the introduction of NBS, or they can hold a referendum to request NBS (BK, 2022). Swiss law is rather complex and therefore to understand better the Swiss law here is a small example of the Water Protection Law.

The goal of Water Protection Law is to "protect water bodies from adverse impacts" (Bundesgesetz Über Den Schutz Der Gewässer (Gewässerschutzgesetz, GSchG), 1997). The Water Protection Law (GSchG) and the associated Water Protection Ordinance (GSchV) are the legal basis for enforcement in the area of urban water management, which must be implemented by the cantons and ultimately by each municipality in Switzerland (*Figure 2*).

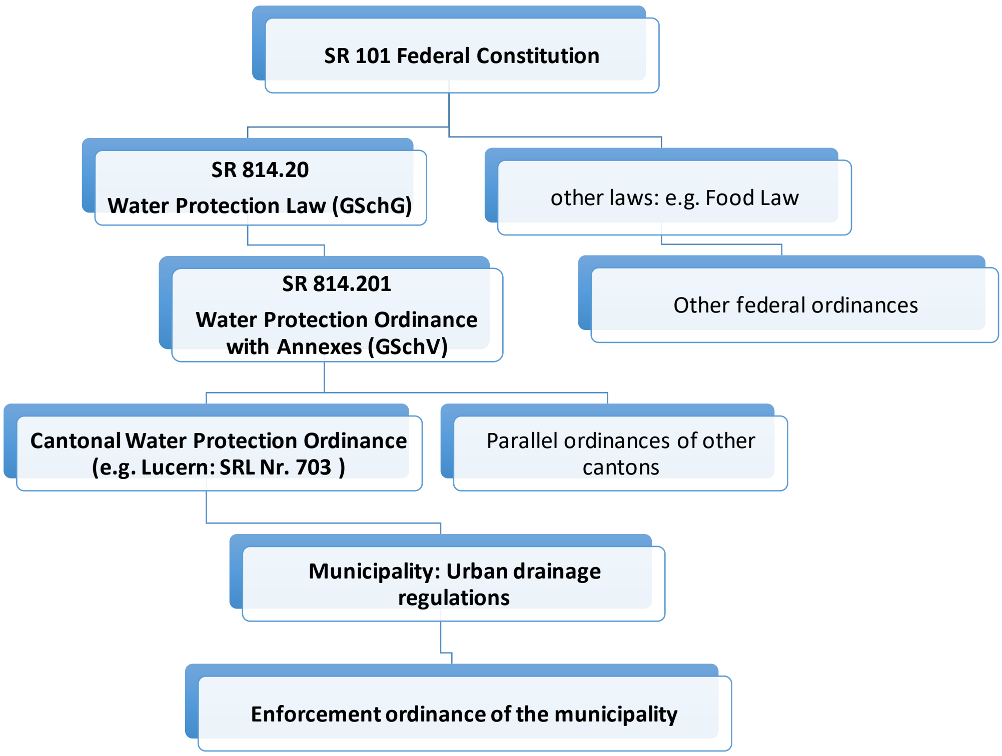


Figure 2: Levels of Swiss Water Protection Law by Andreas Schönborn, ZHAW-IUNR (unpublished)

Water Protection Law looks at the chemical composition of water from three different angles:

1. **from the point of view of the water body**: quality requirements that must be met in the water body.

2. **from the point of view of the treatment plant**: quality requirements that treated wastewater must meet when it is discharged into a water body.
3. **from the consumer's point of view**: quality requirements that must be met by groundwater used or intended for use as drinking water (The requirements that drinking water must meet are set out in the Ordinance of the FDHA of 23 November 2005 on Drinking Water, Spring Water, and Mineral Water SR817.022.102, and in detail in the Ordinance of the FDHA on Foreign Substances and Ingredients in Food SR 817.021.23.).

From the perspective of eco-technology: In principle, plants that completely avoid the generation of wastewater do not fall within the scope of the Water Protection Act. In reality, however, there is an obligation to connect to the sewage system for all households located in the catchment area of a wastewater treatment plant, regardless of whether wastewater is produced or not.

No information or publications on NBS were found on the website of the Federal Office or the City of Zurich (Stadt Zürich, 2022c), but the term "circular economy" was used by the Federal Office for the Environment and the Department of Civil Engineering and Waste Management (FOEN, 2022; Stadt Zürich, 2022d). This is because Switzerland is poor in raw materials and has been pursuing approaches toward a CE since the mid-1980s. It has been achieved to at least partially close certain cycles. For example, of 17.5 million tonnes of demolition materials such as concrete, gravel, sand, asphalt, and masonry, just under 12 million tonnes were recycled in 2018, but more than 5 million tonnes, especially mixed demolition waste, is not yet in a cycle. In the case of municipal waste, slightly more than half of the waste is collected separately and recycled (OECD, 2015; UFAM, 2022c). Nevertheless, according to the Organisation for Economic Cooperation and Development (OECD), the amount of garbage in Switzerland has tripled over the past 25 years and gone up by 350% over the past 50 which means Swiss generate more than 712 kg of municipal waste per capital behind Denmark (752 kg of waste/capital) and United States (725 kg of waste/capital) (OECD, 2015). Therefore, the Confederation of Switzerland aims to promote the CE. The basis for corresponding measures is the precautionary principle and the polluter pays principle, as well as the state of the art innovations, cooperation with the economy, or, if necessary, new regulations (UFAM, 2022c).

Additionally, the Paris Agreement calls on states to develop a long-term climate strategy. The Federal Council adopted Switzerland's long-term climate strategy on 27 January 2021 and approved its submission to the UN Climate Change Secretariat. Switzerland worked on a strategy that shows how the goal of Net Zero greenhouse gas emissions by 2050 can be achieved. The long-term climate strategy presents possible developments up to the year 2050 for the sectors buildings, industry, transport, agriculture and food, financial market, waste, and synthetic gases as well as for international air transport and defines strategic objectives for each sector (UFAM, 2022b).

Although Switzerland is working on measures for Net Zero, climate change is already shaping the environment and will do so even more in the future. Zurich has developed a specialised heat mitigation plan that identifies the most important fields of action for heat mitigation and develops concrete approaches for the city. On this basis, actors can now draw on a wide-ranging toolbox to contribute to heat reduction in their respective spheres of activity, both as a precaution and directly (Stadt Zürich (Hrsg.), 2020). Also, UFAM, 2018 published on reducing the heat island effect through climate-adapted outdoor design, which requires the planning of open spaces with green areas, shaded areas and, freely accessible, cooling water elements and circulation of fresh air from the surrounding area must be ensured.

Wastewater disposal in Zurich is organised as follows: All wastewater in the city of Zurich is treated at the Werdhölzli wastewater treatment plant operated by Entsorgung + Recycling Zürich (ERZ). There, the wastewater goes through a five-stage treatment process, namely mechanical, biological, chemical, ozonation, and filtration. In addition, streams are cleaned and blocked watercourses are remediated. (Stadt Zürich, 2022b)

There is 810 ha of agricultural land in the city of Zurich. This corresponds to about one-tenth of the entire city area. Around two-thirds of the land is owned by the city. The Department of Agriculture of Grün Stadt Zürich is responsible for the administration and management of the city-owned agricultural land. The City of Zurich owns ten farms, nine of which are leased and managed by farming families on their own account (Grün Stadt Zürich, 2020).

2.2. Materials and Methods

In this study, the status of the implementation of NBS in the city of Zurich was surveyed with semi-structured interviews that were based on open-ended questions used in previous studies (Houston et al., 2020). Here, respondents were asked to answer questions thematically related to the use of the NBS (*Appendix I*) The semi-structured approach allows respondents to develop their narrative, which enables discussion beyond the predefined thematic framework of the interview. In the interview, the focus was on NBS in the areas of water management, resource recovery, urban agriculture, and climate mitigation and protection. For this purpose, experts specialised in the field of NBS in Zurich were sought. To identify the primary list of respondents, a list of four main groups was created: i) government and states, ii) water companies, iii) NGOs, and iv) academics. The full list of stakeholders is presented in table 4. Five interviews were conducted, consisting of two academics, one entrepreneur, and two from the municipality. No water company was found because no one agreed to be interviewed. Interviewees were informed that their statements would be recorded, transcribed, anonymised, and the participation was voluntary. The conversations lasted a total of 314 minutes, of which the shortest was 46 min and the longest was 90 minutes. The average duration was 60 minutes (four personal interviews and one online interview). One interview was conducted in English and four in High German. The interview process started in July 2022 and ended in November 2022.

Table 4: Overview of the semi-structured Interviews

Stakeholder group	Interview code number	Date of Interview	Online/ In person	Language	Duration of Interview (min)	Short form	Description of interviewee
Government and states	3	12-Jul 2022	In-person	German	46	Gv1	Project manager in Nature Conservation Unit for Vertical Greening
	5	09-Nov 2022	In-person	German	90	Gv2	Project Manager Spatial Development & Planning
NGOs	2	4-Jul 2022	In-person	German	47	NGO	Landscape architect in the Swiss Landscape Architects Association (BSLA).
Academics	4	18-Jul	online	German	72	Ac 1	Professor ZHAW, Research Group Plant Utilisation Centre Urban Ecosystems.
	1	30-Jun 2022	In-person	English	59	Ac2	Professor at EAWAG

The interviews were transcribed with the program Amberscript, 2021 (https://www.amberscript.com/de/). The transcription had to be played through with the audio so that written errors could be corrected. All interviews in German were translated into English. The transcripts were structurally coded into i) barriers, ii) enablers, iii) main actors of NBS, iv) relevant laws and documents, and v) mentioned NBS. The contents of the interview were marked with different colours: NBS with green, barriers with blue, enablers with purple, actors in grey, and documents/laws in red. After marking, the contents were listed by codes on a separate document. After several careful read-throughs and note-taking, the listed contents were converted into codes that should describe their context. The codes were then summarised and compared with other codes to see if the codes contradicted each other or correctly reflected the content of the data in the codes. Next, the self-generated codes were compiled in an Excel spreadsheet. There, the frequency of the mentioned codes from certain themes (NBS, barriers, and enablers) was summed up. Finally, NBS, enablers and, barriers were plotted in diagrams. Figure 3 shows the working steps visually.

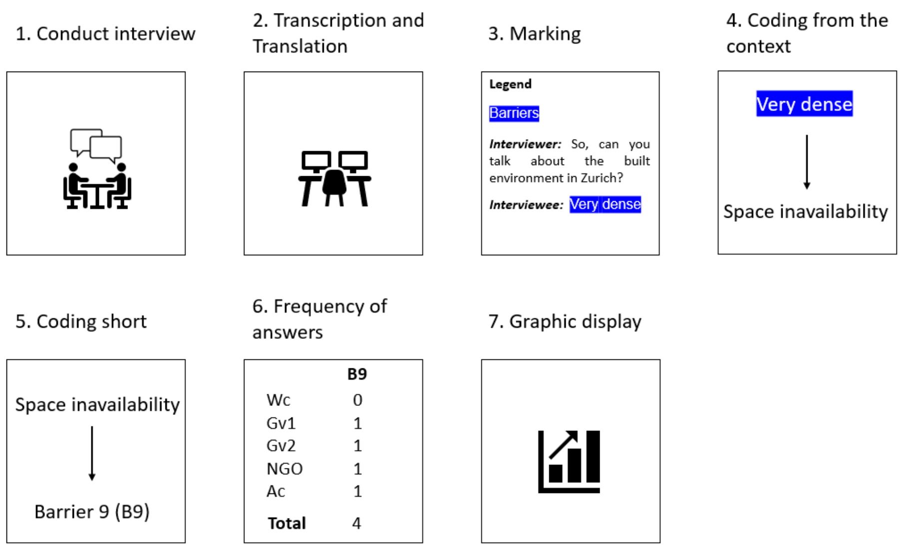


Figure 3: Seven working steps of the Stakeholder-analysis.

The interviews showed that most respondents did not know exactly which environmental technologies belonged to NBS, as they referred to photovoltaics or wind turbines as NBS. This uncertainty about the conceptual classification of NBS in terms of typologies is a common problem (Castellar et al., 2021b). However, certain definitions such as blue-green infrastructure, ecosystem services, or CE are known and were mentioned in most interviews. Some interviewees did not mention specific NBS techniques and simply referred to certain NBS as green or blue areas. This type of description was too vague to be considered in the stakeholder analysis. Only the NBS listed in Castellar et al., 2021b were considered in this study.

3 Results

2.3.1 NBS

Table 5 shows the codes of barriers and enablers of NBS in Zurich. Seventeen types of barriers were identified that could prevent the realisation of NBS and sixteen enablers were found that would support the realisation of NBS in Zurich.

Table 5: Description of the coding of certain barriers and enablers

Codes (Bx)	NBS Barriers	Codes (Ex)	NBS Enablers
B1	Lack of knowledge	**E1**	Flood mitigation
B2	Maintenance costs	**E2**	Heat mitigation
B3	Lack of communication	**E3**	Infrastructure security
B4	Controversial laws	**E4**	Supportive laws
B5	Conflict of interest	**E5**	Past disastrous events
B6	Different priorities	**E6**	Ambition loop
B7	Lack of courage	**E7**	Aesthetics
B8	Lack of teamwork	**E8**	Education
B9	Space availability	**E9**	Information (Journals, Reports, etc)
B10	Long bureaucracy	**E10**	Environment
B11	Outdated documents	**E11**	Expertise mindset
B12	Improper design (wrong, short-term)	**E12**	co-benefits (description and examples)
B13	Lack of resources	**E13**	Product enquiry
B14	Lack of precedent examples	**E14**	Financial support for implementation
B15	Lack of protected areas	**E15**	Guidelines for implementation
B16	Sealing of Soil	**E16**	Important role models
B17	Soil compression		

Figure 4 shows the frequency of mention of the 32 NBS types in these five interviews. Two of them (NBS 8, 10) were not mentioned in the interview and five of them were mentioned in one interview (NBS 16, 21, 22, 24, 25). Ac1 mentioned NBS 16 and 21. On NBS 16, Ac1 explained the importance of connecting green spaces for animals and plants for biodiversity, for example by creating new habitats or ensuring safety for animal movements. On NBS 21, Ac1 explained that it is important to collect rainwater so that gardens (and also parks, NBS 17) can be irrigated. The NGO mentioned NBS 22, 24, and 25. The NGO interviewed pointed out that pre-existing vegetation (NBS 24), such as old trees, is important for the environment and also has other benefits, such as mitigating flooding. Regarding community composting (NBS 25) and vegetable gardens (NBS 22), the NGO mentioned that these are an important part of environmentally friendly and community-building activities. The next five NBS were mentioned in two interviews (NBS 23, 27, 28, 30, 31). NBS 23 were mentioned by Ac2 about the allotment garden association in Zurich and NGO about trying to realise a community garden in their projects. ^System erosion control (NBS 27), Riverbank (NBS 28), and Reprofiling/Extending flood plain area (NBS 30) were mentioned by Ac1 and 2. These were mentioned in the discussion on measures to protect against erosion and flooding, which they are knowledgeable about. NBS 31 was mentioned by Ac1 and NGO in a similar discussion subject about flooding in cities. Three out of five interviewers mentioned the same eleven NBSs (NBS 3, 7, 15, 17, 18, 19, 20, 26, 29, 32, and 5) and four out of five mentioned five NBSs (NBS 1, 2, 4, 14). These NBS were mentioned because they are supposed to contribute to climate change (reduction of heat and flood risk). Finally, five NBS were mentioned in each interview (NBS 6, 9, 11, 12, 13). When interviewees had to give examples of NBSs they knew, these five NBSs were always mentioned. On the NBS list, terms such as "vertical greening façade", "façade" or " vines" were more likely to be used, which would describe NBS 6 (Greened façade).

Codes	**Description**	**Frequency**
NBS 8	Vertical mobile garden	0
NBS 10	Green shady structures, Vegetated pergola	0
NBS 16	Green corridors	1
NBS 21	Private gardens	1
NBS 22	Community Garden	1
NBS 24	Use of pre-existing vegetation	1
NBS 25	Composting	1
NBS 23	Urban Orchards	2
NBS 27	Systems for erosion control	2
NBS 28	Riverbank engineering	2
NBS 30	Reprofiling/Extending flood plain area	2
NBS 31	Diverting and deflecting elements	2
NBS 26	Soil improvment	3
NBS 3	Rain gardens	3
NBS 5	Constructed Wetland	3
NBS 7	Green wall system	3
NBS 15	Street trees	3
NBS 17	Large urban park	3
NBS 18	Pocket garden/park	3
NBS 19	Urban forest	3
NBS 20	Heritage garden, Heritage park	3
NBS 29	Rivers or streams, including remeandering, re-opening Blue corridors	3
NBS 32	Vegetated grid pave	3
NBS 1	Infiltration basin	4
NBS 2	(Wet) Retention Pond	4
NBS 4	Swale	4
NBS 14	Create and preserve habitats and shelters for biodiversity	4
NBS 9	Planter green wall	5
NBS 6	Green façade	5
NBS 11	Extensive green roof	5
NBS 12	Intensive green roof	5
NBS 13	Semi-intensive green roof	5

Figure 4: The frequency of mentioning certain NBS in the interviews. There are 32 NBS where the frequency of mention ranges from 1 to 5.

2.3.2 Barriers

Figure 5 illustrates the frequency of mention of certain barriers.

Codes	NBS Barriers	Frequency
B11	Outdated documents	1
B14	Lack of precedent examples	1
B17	Soil compression	1
B2	Maintenance costs	2
B6	Different priorities	2
B7	Lack of courage	2
B16	Sealing of Soil	2
B4	Controversial laws	3
B5	Conflict of interest	3
B3	Lack of communication	4
B8	Lack of teamwork	4
B9	Space availability	4
B10	Long bureaucracy	4
B15	Lack of protected areas	4
B13	Lack of resources	5
B1	Lack of knowledge	5
B12	Improper construction	5

Figure 5: The frequency of mentioning specific barriers in the interview. 18 barriers were mentioned, with the frequency of mention ranging from 1 to 5.

Seventeen barriers were identified in these five interviews. The definitions of the barriers can be seen in Figure 5. Barriers 11, 14, and 17 are the least frequently mentioned barriers (only in one interview). Barrier outdated data (B11) was mentioned by Ac2. Ac2 talked about his work and that he still has to work with soil maps from 1980 and that you cannot work on a project where the data is outdated because the soil has changed a lot from then to now. Gv2 explained that another barrier was the lack precedent examples (B14). Gv2 explained that in construction there cannot be only one solution, but several are needed because different solutions are required depending on the situation and the environment. Soil compaction (B17) was pointed out by Ac2, who works with plants in cities. He explained that plants cannot grow or grow poorly in compacted soil.

The next three barriers were mentioned in two different interviews, which are B2, B6, B7, and B16. Maintenance costs (B2) were mentioned by NGO and Ac2. The NGO interviewee explained that different from grey infrastructure, blue and green infrastructure have maintenance costs. Ac2 studied economics and stated that Switzerland has a poor economic calculation or at least not a good strategy for obtaining one, which makes it uncertain whether maintenance costs are available at all. The barrier of having different priorities (B6) was mentioned by NGO and Gv2. Both explained that there are certain situations where it makes more sense (and is just as important) to use other things in certain places and situations. *NGO* gave the following example:

> *"The [*Europaallee and Sechsenläutenplatz*] would certainly be two areas where you could critically analyse and reduce sealing. I think there are projects that have come up not just recently, but several years ago. Everyone knew that, but it was much less of an issue, much less of a broad social issue. I think so too when you look at the places that were created in Zurich North a few years ago. There was a certain time, at the beginning of the noughties, when there was certainly also a tendency in landscape architecture towards simple, iconic projects, where the focus was less on the users and more on the offices with their design projects, and you can find that in some places, like [*Sechsenläutenplatz*]. Of course, you have to look at what functions these places have. What is the [*Sechsenläutenplatz]*? It has so much to do for a city society as a place to stay, as a circus place, as a marketplace, as a thousand other things. I think it's the wrong place to plant a lot of trees."*

The next barrier is lack of courage (B7), which was mentioned by Gv1 an NGO. Gv1 explains that more research and experimentation are needed (new technologies, for example in pilot projects, to really gain experience and maybe implement them on a larger scale) and most people do not dare to do this because they are afraid that the experiments might go wrong. Apart from the fear of failure, the NGO worker interviewed sees the reason for the lack of courage is the fear of bad investments. Another barrier mentioned by Ac1 and Ac2 would be the sealing of soil (B16). Both interviewees say that plants cannot grow on sealed ground. The next two barriers (B4 and B5) were mentioned by three interviewees: Controversial law (B4) from NGO, Gv1, and Gv2, and conflict of interest (B5) from NGO, Gv2, and Ac1. Gv2 explained in detail the contradiction of the Swiss law (B4): Gv2 explained:

> *"Laws are partly contradictory. In our case, we have a very specific and very concrete conflict of objectives. Now, the Swiss Spatial Concept says that densification should take place inwards. The canton says: 80 % of the densification should take place in the cities and in urban areas. And the canton says: you have to show how we can accommodate an additional 80,000 people in Zurich by 2040. So, you have the inner development together with the population growth together with the whole net zero problem, that is, the greenhouse gas emissions that come to net zero. And that is simply a conflict that is so difficult to solve, because you would have to set priorities and say, maybe you build as densely as possible in the city of Zurich, but you need to demolish for that. But demolish means again is not so net zero compliant. Then there are other issues, such as affordable housing, a huge topic in the city of Zurich, you have the issue of noise, you have the issue of traffic, and you have the issue of monument protection and so on…".*

Gv2 and Ac2 explained about conflicts of interest (B5) that the implementation of NBS depends on the interests of the individual, community, organisation, or company. Ac2 gave as an example that an environmentalist wants to grow low-fat grass for butterflies instead of a green space with trees to collect rainwater. Another perspective is given by NGOs about individual owners who often choose financial profits over environmental sustainability goals.

Another five barriers (B3, B8, B9, B10, and B15) were mentioned with a frequency of four out of five interviews. Lack of communication (B3) and lack of teamwork (B8) was mentioned by

NGO, Ac1, Ac2, and Gv2. Regarding the obstacle of lack of communication (B3), all agree that there is a lack of communication between cities, cantons, departments, builders, developers, and residents. This leads to the next barrier which is a lack of teamwork (B8) which is here clearly explained by *Ac2*:

> *"In the city of Zurich, it is precisely these product managers who are structured downwards in these hierarchies like the offices, whether this is always nature conservation, I don't think so. It's simply the technical planners. For me, nature conservation is such an appendage in the city, and we need them too. However, it's the water planners, it's the heat planners, it's also the transport planners who we need. They should also have an interest in ensuring that the asphalt surfaces do not heat up, that the asphalt does not melt away. It's the sewage planners, if the sewers don't overflow. They are beginning to understand this. I think it's important to create this combination of grey, blue and green infrastructures, this communal thinking".*

Most interviewees described Zurich as very urban and dense, which leads to the next obstacle, the lack of space (B9), mentioned by Ac1, NGO, Gv1, and Gv2. They explained the lack of space makes it difficult to introduce NBS. The next obstacle would be the long bureaucracy (B10) mentioned by the same interviewee. They said that since Switzerland is direct democratic and federalist, this leads to a long bureaucracy, which means that there are many legal obstacles to overcome and therefore it takes a lot of time until something such as the NBS can be implemented. B15, lack of protected area is a barrier which was mentioned by Gv1, Gv2, Ac1, and Ac2. They believe that the quality of green spaces is important and Ac1 said that the way the city is planned, certain forested areas in green spaces should be protected and enhanced.

Three of these seventeen barriers (B1, B12, and B13) were mentioned in every interview. Regarding the lack of knowledge (B1), all interviewees stated that there is a need to empower field professionals with the necessary knowledge to plan, design, implement, maintain and monitor NBS. Without the right knowledge, it could lead to improper planning (B12). An example from Ac1 to B12 is that water could cool the air, but in the evening there is a risk that it could also heat the air. The NGO pointed out that for the long life of the NBS, not only the proper design but also its proper maintenance is of great importance. Ac2 gave another example of improper design on the issue of vertical greenery with pots made of plastic. When the sun makes it very hot, the plastic can melt, destroying the vertical greenery. Ac1 pointed out that there is a need to discuss in general whether this type of vertical greening with plastic pots can be called NBS. All interviewees mentioned the barrier of lack of resources (B13). Examples given were: not enough water for green spaces or not enough recyclable material (e.g. wood) for structures. GV2 explains that B13 is a conflict in the construction sector specific to Zurich and that scaling could be a possible solution:

"The main focus at the moment is on the operation of the buildings, how do you manage to implement as little greenhouse gas emissions as possible in the operation of buildings? And for me, the circular economy starts earlier, it starts with the construction of buildings, and we are still absolutely at the beginning of the construction of buildings. The experts are in the opinion-forming phase and there are still no solutions that can be accepted by the majority. We know that if everyone builds with wood, it is not possible. Clay and glue won't work. Recycled concrete is also not scalable. The same thing with organic meat. Ideally, we would all eat organic meat. But if you do the math and think about it, okay, if you cultivated organic standards for the rest of your life, you wouldn't have nearly enough land in Switzerland to do that, would you? Correspondingly with wood, it would be exactly the same if you were to prescribe it. Everyone has to build with wood in the sense of a circular economy, which would be good if you could recycle it. But there's not nearly enough wood in Switzerland to do that. This means that you would have to get wood from somewhere and then at the end, the calculation doesn't add up because the transport of the wood would consume more CO2 than if you used concrete again at the end, right? And that is so complex and therefore important for us. And that is enormous. I'm now talking about the positioning as being so important that we have solutions that are scalable and that everyone can implement it."

2.3.3 Enablers

Sixteen enablers were mentioned in these five interviews and the definitions of the enablers can be seen in figure 6.

Codes	**NBS Enablers**	**Frequency**
E6	Ambition loop	1
E7	Aesthetics	1
E16	Important role models	1
E14	Financial support for implementation	1
E5	Past disastrous events	2
E3	Infrastructure security	2
E10	Environment	2
E12	Co-benefits (description and examples)	2
E13	Product enquiry	2
E2	Heat mitigation	3
E11	Expertise mindset	3
E15	Guidelines for implementation	3
E1	Flood mitigation	4
E4	Supportive laws	4
E8	Education	4
E9	Information (Journals, Reports, etc)	4

Figure 6: The frequency of mentions of specific enablers during the interviews. 16 enablers were identified, and the frequency of mentions ranged from 1 to 4.

Three of them were mentioned once (E6, E7, E14, E16). *Gv2* mentioned the enabler ambition loop (E6) and said the following thing:

"I think it's a very nice concept "the ambition loop". I'll put it in my own words now, but the idea behind it is that you have the environmental issues, and you can't say the administration must finally make laws, but you need the climate strike, you need investors who want to build sustainably, which puts pressure on the politicians. You need the administration to come up with good ideas, you need research like you're doing now that examines approaches, and so issues that would never have found a majority politically suddenly become possible, right? Climate adaptation ten years ago! You didn't have to talk about climate adaptation. And now, because there is such a discourse here, it's like a self-reinforcing spiral and suddenly things become possible that would not have been possible before."

Gv1 believes that the next enabler factor for NBS is aesthetics (E7). If the aesthetics of NBS are appealing, more people would support NBS. The next factor mentioned by Gv1 was financial support for the implementation of NBS (E14). Gv1 gave the example of Green City Zurich (Grün Stadt Zürich), which gives financial support to individuals and companies to install NBS such as green façades or green roofs. The next enabler, important role models (E16), was mentioned by Gv2, who believes that stakeholders such as cooperatives and large institutions such as Axa have a role model effect. Gv2 explained the following:

"So, if for example, Axa suddenly says, "Hey, we're now going for a circular economy - our whole portfolio, all the buildings are now built in such a way that they can be deconstructed again", then maybe a private company or we will do the same."

Enablers E3, E5, E10, E12, E13 were mentioned two times. Infrastructure safety (E3) was mentioned by Ac1 and Gv1. Both mentioned it in particular because of events such as flooding and erosion. They said that with NBS the damage would be less in case of floods. The next enabler is catastrophic events (E5). Gv1 and Ac1 said that people could take climate change seriously when environmental disasters occur. The next enabler is the environmental benefits (E10) mentioned by Gv1 and Ac1. An example was biodiversity and habitats for animals. The next enabler mentioned by Ac1 was co-benefits (E12) because they can contribute to the achievement of several Sustainable Development Goals (SDGs) and support resilient adjustments to climate change. Gv1 and Gv2 mentioned the next enabler, namely product demand (E13). They believe that the demand for NBS would contribute to the growth of the NBS market.

Enablers E2, E11, and E15 were mentioned three times (E2, E11, and E15). The enabler heat mitigation (E2) was mentioned by Ac2, Gv1, and Gv2. All three interviewee said that mitigating urban heat with NBS would help against persistent heat stress as it leads to an increase in mortality and morbidity rates. Gv1, Gv2, and Av1 believe that the expertise mindset (E11) of NBS would help promote NBS. As examples, the need for professionals to treat grey water in wetlands, the construction of recyclable and circular buildings, and the implementation of appropriate and well-adapted green facades and planted roofs were mentioned. The next enabler is guidelines for NBS implementation (E15) which was mentioned by Ac1, Ac2, and

Gv2. The interviewees explained that having a guideline would help the engineers, the planners, and the managers to implement NBS.

Enablers E1, E4, E8, and E9 were mentioned four times. Interviewees Ac1, Ac2, Gv1, and Gv2 mentioned the problem of flooding in Zurich and how NBS can help to mitigate flooding (E1). They also mentioned information (E9) as contributing to NBS. They think that more information or literature such as publications about NBS in Switzerland is needed and needs to be accessible to everyone. Another example mentioned by Ac1 is that not only literature or platforms can provide information, but also models that can help planners or other stakeholders to understand the role of NBS. Ac1 explains:

"As an example, you try to look at the intersection of different maps and when you put these different maps together, for example, the Cadastral map, which is relevant for planning combined with say a heat map which you generate from an energy balance model combined with hydrologic analysis of where the water flows and where it's going to drain to. You start to understand a bit of how the different areas relate to each other in terms of you might have a critical area because it's at the bottom of the catchment, so all the water is going to flow there, but it's also quite a hot area. So, you could collect that water and actually use it in the area to cool the heat. So, you can start to look at these kinds of relationships in the models."

Gv2 added that the public can be made aware of the NBS also through the media and the press.

The next enabler is the supporting law (E4) mentioned by Ac2, Gv1, Gv2, and NGO. NGOs say that it is often necessary to explain to clients why it is important to have thick soil for a green roof so that the water is well filtered, and the plants can grow. However, as this is not required by law, many discussions are needed to convince the clients of this necessity. Another example from Ac1 is that most of the trees in the street are not greened, which is important for the beginning stages of the trees, where the trunks would be protected. However, since the greening of the trees is not required by law, it is not done. Gv1 believes that the implementation of the NBS would move faster with supporting laws. Gv2 agrees that laws are necessary, but he knows from his working position that some laws will come, only when the majority votes for them. The enabler education (E8) was mentioned by Ac1, Gv1, Gv2 and, NGO. The NGO interviewed suggested that improving education through educational programmes, workshops, or transferring research results into social discourse would help to promote NBS. Gv2 tells that Green City Zurich (Grün Stadt Zürich) is already doing something by preparing an exhibition for visitors at the Stadtgärtnerei dedicated to thermal protection, the basis of the City of Zurich's thermal protection planning published in 2020. The exhibition showed how plants, water, shade, and the preservation of air currents contribute to cooling the environment. The rest of the interviewees mentioned only that education is very necessary for the contribution of NBS.

Table 6 shows the number of times NBS, barriers, and enablers were mentioned by specific respondents. NBS was mentioned most frequently by Ac2, barrier by Ac1, and enablers by Gv1 and Gv2.

Table 6: Frequency of mention of NBS, barriers and enablers by Interviewee.

Interviewees	NBS	Barriers	Enablers
Gv1	5	7	11
Gv2	12	12	11
NGO	19	10	2
Ac1	21	14	9
Ac2	24	7	7

2.4 Discussion

2.4.1. Stakeholder analysis

Stakeholder analysis is a useful tool for managing stakeholders and identifying opportunities to mobilise their support for a particular goal. Most research suggests that involving the people that has a stake in a particular process or its outcomes can lead to results that better reflect the reality on the ground (Bah et al., 2021). Additional information can be drawn from the interview transcripts and related materials to situate the assessments in the policy context of the NBS and to allow interviewees to express their opinions on the options presented and their own assessments (Stirling et al., 2007). However, various biases and uncertainties require a cautious approach to the use and application of the results (Varvasovszky & Brugha, 2000). Furthermore, the lack of a stakeholder identification and engagement process often leads to a very long initiation process and significant delays in implementation (Zingraff-Hamed et al., 2020). It must also be kept in mind that not all members of the main groups participated in this survey, and if they did, only a few participated in this study. This lack of numbers and perspective has an impact on the result (Griffee, 2005).

2.4.2 Nature-based Solution

The reason why extensive green roofs (NBS 11), intensive green roofs (NBS 12), and semi-intensive green roofs (NBS 13) were mentioned most often could be because they are embedded in the Zurich laws (TED, 2022b). According to the building and zoning regulations of the city of Zurich, the greening of flat roofs has been obligatory for new buildings and renovations since 1991. As long as it is technically, operationally, and economically possible, unused areas must be greened with ecologically valuable vegetation (Bauordnung Der Stadt Zürich, 2018). In addition, landscaped roof gardens are not only habitats for animals and plants, but also serve recreational purposes (Grün Stadt Zürich et al., 2020).

The reason for the widespread use of façade greening (NBS 6) and wall greening (NBS 9) is that these NBS were recommended in the UFAM, 2020 publication alongside others, such as green roofs (NBS 6, 11, 12), infiltration basin (NBS 1), retention pond (NBS 2) and Swale (NBS 4), to counter the challenges and problems of climate change in Switzerland (Verein für Ingenieurbiologie et al., 2017). In addition, Green City Zurich (Grün Stadt Zürich) advises and supports private individuals and companies in the greening of their buildings and the financial upgrading of the building environment (TED, 2021).

2.4.3. Barriers

The order in this chapter is from least mentioned to most mentioned barriers.

First is the barrier of outdated document (B11). Therefore a key strategy is to improve the data (Toxopeus & Polzin, 2021). Next would be a lack of precedent examples (B14). This problem shows that debates on NBS are in line with frequent calls from urban practitioners, policymakers, and city networks to 'scale up' successful pilot or demonstration projects, and that actions need to be aligned with climate change, transition to sustainability, or resilience. (Beceiro et al., 2022; UNEP, 2019). However, scaling up NBS is complex and requires inter- and transdisciplinary expertise to address a range of environmental, institutional, and socio-cultural challenges. In addition, institutions are needed to provide platforms for continuous exchange between heterogeneous actors from the public and private sectors, academia, and society (Fastenrath et al., 2020). The next barrier is soil compression (B17). When the soil is worked or driven on with heavy machinery or vehicles, the soil is compacted, that is, its pores or open spaces are compressed. Due to soil compaction, water can no longer percolate, air can no longer circulate, and decomposition processes and root growth are inhibited, making planting more difficult (FOEN, 2021a). Therefore, it is necessary to prevent soil compression or loosening the soil. The extent of soil compaction in Switzerland cannot yet be quantified, because the measurement and evaluation methods are still being tested (FOEN, 2021b).

The next barrier is maintenance costs (B2). Even though several studies are showing that NBS is often cheaper than grey solutions (H. Li et al., 2017), the implementation and especially the maintenance of NBS solutions cost more compared to a grey infrastructure (Fernandes et al., 2019; Lorenzoni et al., 2007). A qualitative study on the barriers to implement green-blue infrastructure in Newcastle revealed that initial funding requirements were lower or similar to those for grey infrastructure, but that longer-term funding was required to reap the full benefits of blue-green infrastructure due to the higher maintenance costs (O’Donnell et al., 2017). For this, strategies to coordinate public and private funding for urban NBS can be targeted. Options would be to share the costs with stakeholders who can also benefit directly. This often goes beyond general taxes and aims to identify specific private and public parties that can benefit and therefore be encouraged through financial instruments. (Toxopeus & Polzin, 2021).

Different priorities (B6) go with the limited availability of land and are a barrier to the use of NBS in cities (Price, 2021). It is necessary to prioritise green infrastructure allocation to realise NBS (Kapos et al., 2019). However, this also raises huge issues of justice and equity, particularly with land ownership rights of local communities (especially poor and marginalised people), distribution of benefits, and power dynamics (Bush & Doyon, 2019). Justice aspects are not always explicitly considered, and there are often tensions between the ideal of sustainable and ideal cities and the reality of urban NBSs, which partly depend on the existing power structures they try to influence (van der Jagt et al., 2021). Therefore, NBS needs to adopt a context-sensitive approach where issues of equity are continuously considered (Price, 2021).

The lack of courage (B7) comes from the fear of the unknown, the mismatch between short-term measures and long-term goals, the discontinuity between short-term measures and long-term plans, sectoral silos, and the paradigm of growth. However, knowledge is gained from experiences with the implementation of successful projects where urban green spaces have been introduced, qualitatively improved, or restored, as well as the lessons learned from less successful projects and is considered crucial for the effective use of NBS in urban planning. However, this knowledge can only be put into practice if new actors or stakeholders cooperate with the networks that have already been created or that have gained experience (more in lack of knowledge (B1)) (Kabisch et al., 2016). In regards to fear of bad investment, large innovation and demonstration projects in particular have the power to build trust and political willingness for a broader implementation of the NBS and to overcome the lack of trust in the NBS also in the industry (Kisser et al., 2020)

In the canton of Zurich 14% of surfaces are sealed (B16) (Statistik, 2021). The total sealed area in Switzerland has increased by 39.9% since the first land use statistics survey (1985). This is due to the increase in residential space, the area used for transport routes, structural change in agriculture, and among other things (Statistik, 2018). The standard pavement in the city of Zurich is asphalt with granite edging (TED, 2022a). The problem with asphalt, they absorb solar radiation particularly strongly, and they heat up and store the heat during the day (Bergamin, 2017). In addition, climate change in urban areas increases the risk of flooding due to surface runoff after heavy rainfall (UFAM, 2022a). It is difficult for plants to grow on asphalt surfaces and certain NBS are needed that can be adapted to climate change (Hopkins et al., 2022). To reduce soil sealing, informed residents would play a crucial role in the effort of improved housing quality, sufficient recreational areas, and the reduction of motorised traffic (Artmann & Breuste, 2015).

One of them is the controversial legal situation (B4). As a result, Gv4 has already explained the problem of the controversial laws in Switzerland, which has also been highlighted in other publications (Balzan et al., 2022; Kisser et al., 2020; Urban GreenUp, 2019). Therefore, a revision of the law is recommended (Gholipour et al., 2023).

The next barrier is the conflict of interest (B5), especially when dealing with a large number of actors. In Zurich, where 55% are private owners (Brenner, 2016) implementing NBS with this many stakeholders is a rather complex challenge (Dhakal & Chevalier, 2016). A key element of any NBS development process thus is to co-create solutions with citizens by including them in the early stages of the planning process (Kabisch et al., 2016). Also, the engagement of local entrepreneurs and other members of the local community appears to be critical in effectively developing and maintaining NBS (van Ham & Klimmek, 2017).

The lack of communication (B3) exists between cities, cantons, departments, builders, developers, and residents. If departments and institutions work on the basis of different visions, goals, legal structures, and ways of thinking, they are trapped in their silos (O'Donnell et al., 2018). This leads to weak communication between stakeholders and is one of the main reasons for project delays(Chauhan & Saini, 2015). That this is a crucial challenge in developing NBS as a multifunctional solution, as multiple disciplines and institutions intersect (Davis & Naumann, 2017).

Lack of teamwork (B8) makes it difficult to promote NBS. The Learning and Action Alliance (LAA) can help overcome this obstacle. LAAs are open agreements in which participants with a common interest in innovation and implementing change create a shared understanding of a problem and its possible solutions based on rational critique and discussion (Ashley et al., 2012). LAAs foster collaboration between stakeholders from different disciplines and backgrounds by breaking down barriers to horizontal and vertical information exchange and accelerating the identification, adaptation, and adoption of new information (O'Donnell et al., 2018). Continuous processes of social learning enable stakeholders to create flexible networks and build the trust required for collaboration through formal and informal relationships (Pahl-Wostl et al., 2007). The article by Benson et al., 2016 examines a stakeholder engagement process in the context of flood risk management in the UK to assess whether it helps to improve effective engagement through social learning. They showed that personal and group learning outcomes were observed to varying degrees, suggesting that stakeholder engagement was relatively successful. Recommendations for future stakeholder engagement are suggested, which are useful for both policy and management processes in other countries.

Space unavailability (B9) was mentioned in the Newcastle case study by O'Donnell et al., 2017, which identified barriers to green infrastructure. Unlike in this study, it was not one of the most significant barriers of all. There is competition for limited space and urban land is expensive (UN environment programme et al., 2021). Additionally, the suitability of a site for NBS implementation may be limited by many factors, such as the type of soil, contamination in the soil, or underground facilities such as water and power lines that may be an obstacle to tree planting (Urban GreenUp, 2019). Glasgow's (UK) approach to developing a larger scale NBS is underpinned by the strategic Open Space Strategy (OSS) and the accompanying local context analyses. The OSS is a cross-cutting strategic document that aims to provide a coherent vision and coordinate the different responsibilities for open space to ensure well-managed, well-located, and well-connected open spaces that function as part of a wider green network and provide multi-functional benefits (Frantzeskaki et al., 2020). The Glasgow NBS example is thus a city-wide network of multifunctional green spaces and a pilot project for a sustainable urban drainage system that offers multiple climate change mitigation and reconnection benefits. Pozna's strategy is a city council initiative to complement the existing green system by developing a series of smaller NBS, e.g. green 'stepping stones' within the dense city core, which improve the accessibility of green spaces and enrich the multifunctionality of green wedges (Frantzeskaki et al., 2020).

The next barrier would be the long bureaucracy (B10). As already explained in the introduction section 2.1 of this paper, Switzerland is direct democratic and federalist, which leads to a long bureaucracy (Burri, 2015). Still, NBS has gained much political attention in recent years and has rapidly moved up the political agenda. This includes being highlighted in recent high-level global assessment reports, such as those of the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Platform on Biodiversity and Ecosystem Services Science and Policy (IPBES). It is also recognised in international agreements and conventions, including the United Nations Framework Convention on Climate Change (UNFCCC) and its Climate Action Pathways (Chausson et al., 2020; Kapos et al., 2019; Seddon et al., 2021). For example, 70 of the 167 initial National Climate Contributions (NDCs) submitted under the Paris Agreement include actions that are broadly consistent with Ecosystem-based adaptation, and a further 33 countries refer to conservation activities - and these commitments are more prevalent in developing countries than in high-income countries (Kapos et al., 2019). NBS is also the focus of a growing number of programmes by governmental and non-governmental organisations, as well as the private sector (Seddon et al., 2021). In most cases, however, ambitions for NBS do not match practice (OECD, 2020). For example, in a survey commissioned by the State Secretariat for Economic Affairs (Seco), two-thirds of over 2,000 companies surveyed in Switzerland perceived the administrative burden as rather high or high.

In the case of individual legal regulations, more than half of the responding companies indicated a high or rather high burden in the areas of construction projects, food hygiene, import and export, accounting and, value-added tax. Among the proposed improvements, mentions of simplifying or standardising procedures and harmonising or reducing legislation were the most frequent. In addition, companies frequently pointed to digitalisation as a way to reduce administrative burdens (Tagblatt, 2019).

The lack of protected areas (B15) such as green, blue green areas and forests. NBS can be grouped by sectors and thematic areas of societal importance: (I) water management, (II) forests and forestry, (III) agriculture, (IV) urban areas (such as parks, etc.) and can therefore be improved and supported (European Environment Agency et al., 2021; McVittie et al., 2018).

Following are the barriers that were mentioned by all interviewees.

One of them is the lack of knowledge (B1), which has been mentioned in several papers (Kabisch et al., 2016; Lorenzoni et al., 2007; O'Donnell et al., 2017; Sarabi et al., 2020). There is a need to equip professionals in the field with the necessary knowledge to plan, design, implement, maintain and monitor NBS (C. Davies & Lafortezza, 2019; Johns, 2019). NBS is ecologically and institutionally interdependent, so their adoption and effective implementation can contribute to transformative changes that reshape socio-ecological relations (Olsson et al., 2014) and replace and reshape current socio-technical systems. This implementation can also fill existing knowledge gaps and facilitate context-appropriate solutions at relevant levels (Savaget et al., 2019).

The next barrier is improper design (B12). It is critical that NBS is well thought out and context specific, utilising both scientific and local/indigenous knowledge (Price, 2021). Careless or poorly planned or implemented NBS could result in undesirable impacts on-site, an imbalance in natural resources consumption, or the use of harmful materials (Mesimäki & Lehvävirta, 2019). Impacts can be environmental and social. For example, the study by Jacobs et al., 2020 shows that small urban water bodies such as ponds or canals are often considered to cool the environment during hot periods, when water bodies are cooler than the air during the day, although they can be warmer at night. Another example is the development of green roofs and walls in European cities (Eggermont et al., 2015). Starting from the sole objective of developing green spaces in urban areas to mitigate the effects of global warming, green roofs or walls could be created with, for example, clones of individual plant species or monocultures, regardless of their biogeographical distribution. Such structures would do little to increase biodiversity and provide other ecosystem services. This may also lead to low resistance and resilience to future extreme events, higher management costs, and the risk of biological invasions. Without a coordinated city-level approach, companies would likely design green buildings on a case-by-case basis, with a high degree of uncertainty about their effectiveness at the city level. Such an approach, which largely fails to meet the objectives of sustainability, biodiversity enhancement, and effectiveness at a relevant level such as the city, would not fit within the framework of the NBS (Eggermont et al., 2015). To ensure that solutions are fully implemented, they should be designed and placed appropriately. The size of a solution should be appropriate to the level of disturbance during extreme events and argue that "insurance is achieved by the NBS providing a 'buffer' between the exposed area and the potential risk (Andersson et al., 2017). Another important question is where NBS should be placed. Hoyle et al., 2017 recommend that shrubberies should be placed in semi-rural parts of urban areas for optimal performance. It is important to consider the placement of NBS at a strategic level and plan NBS at a landscape level to assess the interaction between NBS and urban environments and optimise the synergies and trade-offs between them (Emilsson & Ode Sang, 2017).

The barrier of lack of resources (B13) depends on the place-specific environment in which urban life is embedded, giving rise to place-specific forms (Raven et al., 2017). According to a Paper by Johns, 2019, resource scarcity is not the biggest obstacle. There was a consensus that the resources are there if the expenditure and revenue instruments could be used better or differently.

2.4.4. Enablers

The order in this chapter is from least mentioned to most mentioned enablers.

In one of the interviews (Gv2) mentioned the enabler "ambition loop" (E6). Ambition loop United Nations Global Compact et al., 2018 published a paper on the "ambition loop", a positive feedback loop between the private sector and governments that should accelerate progress towards the Paris Agreement goals and the Sustainable Development Goals. In the ambition loop, such as increasing commercial demand, setting bold climate and clean energy targets, and increasing business investment in climate change solutions would send strong signals to the government and support stronger climate policies. In the paper, Northrop et al., 2022 explained the importance of everyone's contribution corresponding to the ambition loop. The Blue Ambition loop companies are increasing their ambition and investment in renewable marine energy, setting targets for biodiversity, producing sustainable food from the sea, decarbonising maritime transport, and switching to electric coastal fleets. Non-governmental and international organisations are helping to accelerate efforts to sustainably use, conserve and restore coastal and marine ecosystems to maximise their potential to store and sequester carbon. This momentum sends a strong positive signal from non-state actors to governments in support of ambitious ocean-based climate policies. Therefore, governments can use this as a strong vote of confidence to drive ambitious policies that give the sector the clarity and confidence it needs to unlock further investment in a sustainable, low-carbon, and climate-resilient ocean economy. This kind of ambition could also support NBS in Zurich. For enhancement, the Beceiro et al., 2022, a case study of Porto identified linkages with civil society and the development of awareness-raising campaigns and events focusing on NBS and ecosystem services as the main ways to improve urban resilience (more about this in the enabler information (E9)).

Aesthetics E7 of NBS are crucial for their successful acceptance by the public (Frantzeskaki, 2019). In the paper of Rall & Haase, 2011**,** they reported on a policy of "Interim Land Use" (ILU) initiated in Leipzig, Germany. The policy was introduced to cities in the late 1990s to combat urban blight. A "permission agreement" was signed between the city administration and private owners to allow public use of private land while respecting the owners' building rights. The city created new green spaces for public use on these private properties and connected fragmented green spaces. The ILU was considered successful.

The next enabler is support for implementation (E14). The city of Zurich has been upgrading its own areas for years but can only achieve its target of 15% ecologically valuable areas in the settlement area if private landowners also contribute. Currently, just under 11% of the areas are considered ecologically valuable. To increase the ecologically valuable areas, Green City Zurich (Grün Stadt Zürich) advises and supports private individuals and companies in greening their buildings and ecologically enhancing the built environment (TED, 2021). Getting financial support is not a granted thing. Despite the cost-effectiveness and multiple benefits of green infrastructure (GI) compared to grey infrastructure, the lack of financial support for GI is surprising (L. Li et al., 2020). Legal constraints discourage investing public money in private land, and developers often do not have a strong motivation to build GI projects, as the initial investment costs are often higher than the economic gains (Keeley et al., 2013).

The role model character (E16) can be considered as part of the ambition loop. One example is Business for Nature, a global organisation (Business For Nature, 2022; Seddon et al., 2021). On the Business for Nature website, they state that they believe that businesses have a crucial role to play and must participate in the global discussion on nature by demonstrating their support for ambitious nature policies. For this reason, Business for Nature has set out the case for corporate support for NBS and encouraged 530 companies to work to reverse the loss of nature and restore vital natural systems on which economic activity depends, primarily through partnerships with businesses. However, if NBSs involve a more equitable distribution of power between local communities and government, such as community-managed forests, they are more likely to achieve positive outcomes for both people and the ecosystems on which they depend (Hajjar et al., 2021). This is partly because such measures empower and motivate the people who have access to and control the most important resources (Seddon et al., 2021). Other contributions also highlighted the importance of the private sector, communities, and politicians as motivators (Balzan et al., 2022; Frantzeskaki et al., 2020; Zwierzchowska et al., 2019).

The study by L. Li et al., 2020 on GI in the UK and China showed that infrastructure safety (E3) is the most important factor as it is crucial for reducing stormwater runoff and peak flows in the drainage system in both countries and also contributes to social well-being and climate adaptation. However, even though there are many case studies and much experience with NBS for small-scale flooding, there is a lack of evidence on the effectiveness and efficiency of NBS on a large scale. There is a clear need to develop a more comprehensive evidence base on the social, economic, and environmental effects of potential NBS, including comparison with more traditional solutions. Until land management for NBS is properly considered and extended to the catchment (or aquifer) level, NBS will remain ineffective and inefficient for flood risk management (Hartmann et al., 2019).

Disaster events (E5) are considered an important factor in the paper by Sarabi et al., 2019. The term 'disaster risk management' usually refers to both disaster risk reduction (prevention, preparedness, and mitigation) and humanitarian and developmental action (emergency response, relief and recovery) Due to catastrophic events, insured losses in the first half of 2022 totalled 35 billion dollars worldwide (Baumann, 2022). These were losses such as floods in Australia, worldwide droughts, storms, floods, hail, and forest fires in Europe and the USA. Climate change is exacerbating the situation, which is why prevention is being worked on (Baumann, 2022). Resource scarcity (e.g. fossil fuels), natural disasters, sea level rise, or air quality deterioration can be considered as triggers for investment in sustainable alternatives (Muñoz-Erickson et al., 2016). However, according to the UK Department for International Development (DFID), the main barriers to mainstreaming disaster risk into development planning are institutional and financial structures, assumptions about the risk-reducing impact of pro-poor development, and insufficient engagement with and information about disasters (Pelling, 2004).

The enabler environmental benefits (E10) were mentioned by Bah et al., 2021 as an important factor in the stakeholder mapping report in Burgas (Bulgaria), Lahti (Finland), Limerick (Ireland), Tallinn (Estonia), Umeå (Sweden) and Versailles (France). One example is Limerick, the third largest city in the Republic of Ireland, 200 km from Dublin, which has been designated a UNESCO Learning City and European Green Leaf (2020). Limerick's main species-rich natural habitats are found around an extensive network of rivers, including the Shannon, Abbey River and Ballynaclough River, with associated wetlands, grasslands, and woodlands. In Limerick, the urban green space per capita is 73 m², which is above the World Health Organisation ideal (50 m²) and well above the European average (18.2 m²). Also, if there were more green corridors and areas, it would be good for the connectivity and movement of animals and plants since the corridors would serve as habitats (Rayfield et al., 2011). NBS would also increase biodiversity and human well-being (Bennett et al., 2015; Szulczewska et al., 2014). For a good result, however, the right design is essential for public acceptance (more in aesthetic (E7)) and also the full potential can be exploited.

NBS has a lot of co-benefits (E12). Therefore, is getting increasingly promoted in regional and national policies (Balzan et al., 2022). NBS also offers sustainable and cost-effective solutions for air quality (Calfapietra et al., 2015; Wang et al., 2015), water management (Armson et al., 2013; Bouwma et al., 2018; Pearlmutter et al., 2021), urban biodiversity (Connop et al., 2016). It also provides solutions for cross-cutting challenges such as biodiversity protection, public health and well-being (Canzonieri, 2007; Carrus et al., 2015), and road traffic noise reduction (Van Renterghem et al., 2012). The paper by Liquete et al., 2016 also states that NBS specifically enables the quantified ecosystem services of water purification, flood regulation, natural habitat, and recreation. Several studies have shown that NBS can improve thermal comfort and save energy in cooling and thermal performance (Aboelata, 2021; Carlos, 2015; F. Kong et al., 2016; Peng et al., 2020). Economic evaluations of green spaces in several cities around the world have shown that nature provides billions of dollars in cost savings for health services. Protected areas are increasingly being established in and around cities to protect biodiversity and ecosystem services, including health benefits (MacKinnon et al., 2019). Co-benefits have also been seen as an enabler in the paper by Raymond et al., 2017 where they did a review of over 1700 documents from science and practice within and across 10 societal challenges relevant to cities globally. They transferred the framework from theoretical support to practical relevance by presenting a seven-step process that can guide the implementation of NBS. However, they point out that the issues surrounding NBS are multidimensional and complex, so the selection and evaluation of NBS and related measures require the participation of a wide range of stakeholders, multidisciplinary teams, and policy and decision makers.

Product enquiry (E13) is an important enabler because improved energy efficiency and reduced energy demand will be the main contributors to combating global climate change (Sorrell, 2015). An improved capacity to understand, intervene in, and manage multiple goals in complex socio-ecological systems. On the other hand, it could also offer new opportunities to address overarching societal challenges. This could be problematic if understood narrowly in terms of market-based approaches and money flows (Nesshöver et al., 2017).

Mitigating urban heat (E2) is a global and a Swiss goal, as high and persistent heat stress leads to an increase in mortality and morbidity rates (Environment, 2021; UFAM, 2018). Therefore, several papers with stakeholder analyses explain that the NBS came into existence because of the need for global heat mitigation (Faivre et al., 2017; Sarabi et al., 2019; Zingraff-Hamed et al., 2020). Also, because of the urban heat island effect in Zurich, the city developed a technical plan to identify the most important fields of heat reduction and develops specific approaches for action. The technical planning is based on the following objectives: to avoid heating in the entire city area, to relieve vulnerable urban areas in a targeted manner, and to preserve the existing cold air system of the city of Zurich (Stadt Zürich & Grün Stadt Zürich, 2020). For example, there is the principle of "sponge city", which was also mentioned by Ac1, Ac2, and Gv1. The principle of the "sponge city" is to minimise flooding (E1). The concept is that flooding rainfall is retained in the city like a sponge and only flows slowly back into the water bodies and groundwater. This basic idea is to be adapted to mitigate climate heating in Zurich. The first pilot project will focus on the interaction between rainwater and its evaporation via the green city (Stadtgrün)and the simultaneous improvement of the living conditions of the street trees. This implementation is new in Switzerland and is intended to provide insights into the effectiveness and feasibility of implementation in the street space of Zurich (TED, 2020).

Expertise mindset (E11) on NBS can be for example specialisation in water treatment with grey water and wetlands, construction of recyclable and circular buildings, implementation of appropriate and well-suited green facades and planted roofs, and others. Even though there is already knowledge on how to implement such solutions at the urban level, such as green façades and green roofs, there are still gaps in terms of questions such as: What technical knowledge and skills are needed for multifunctional urban planning, and how can this knowledge be incorporated and linked to knowledge about environmental and social systems to achieve the best possible synergies e.g. climate adaptation and mitigation (Kabisch et al., 2016). This challenge can also be described as a lack of technical knowledge, as documented through interviews in the Keeley et al., 2013 study. Therefore, more expertise mindset to promote NBS is needed.

The next enabler is a guideline for implementation (E15). The availability of regional guidelines is an important factor in supporting local implementation (Balzan et al., 2022). A guide takes a pragmatic approach to stakeholder engagement by presenting general principles and best practices that should be considered at all stages of an NBS project and describing specific steps for stakeholder engagement at all stages of an NBS project. Effective stakeholder engagement is of paramount importance for the long-term success of any NBS project (Pacific Institute & United Nations Global CEO Water Mandate, 2022).

The next important factor is flood mitigation (E1). The number of floods in Switzerland has been increasing, which is related to changes in the hydrological cycle and the more frequent occurrence of hydrometeorological extremes (C. S. S. Ferreira et al., 2021; UFAM, 2021). In 2005, the city of Zurich only barely escaped major flood damage: if the centre of precipitation had been over the Sihl catchment area instead of in the Bernese Oberland, the Sihl would have flooded large parts of the city of Zurich (Stadt Zürich, 2022a). NBS as a help against flood mitigation had been shown in several other papers (Balzan et al., 2022; Sarabi et al., 2019; Zingraff-Hamed et al., 2020). Water management in urban areas is established to mitigate the impacts of development on water cycling namely through the implementation of NBS such as green corridors, urban parks, urban gardens, urban forests, urban grasslands, and other recreation zones (C. Ferreira et al., 2021). The water elements integrating urban Green Infrastructure include rivers, lakes, canals, ponds, and floodplains, which provide an additional capacity to cope with water during rainfall events (Abbott et al., 2013). An example of the use of NBS to mitigate flooding in the city of Zurich is a rake which can be found at Sihlsee above Langnau am Albis. The rake prevents blockages caused by driftwood at critical locations such as bridges or the culverts under Zurich's main railway station (Bonderer et al., 2017).

The next enabler is supportive laws (E4). This was also described in the paper by R. Brown & Farrelly, 2008; R. R. Brown & Farrelly, 2009 that there are often social and institutional barriers such as lack of political and organisational support and lack of appropriate regulations. An example is in Vancouver the Urban Forestry Policy where the tree canopy is defined as green infrastructure in the Vancouver Urban Forestry Policy The policy allows the removal of trees on private property only if the trees are hazardous, diseased, or impacting infrastructure. The policy also limits the removal of trees for development, creates a framework for conservation and, sets a target of 150,000 trees to be planted on public and private land to increase the urban tree canopy from the current 18%. (Blakelock & Maynes, 2017).

The enabler education (E8) would also support implementing NBS. City Zurich (Grün Stadt Zürich) prepared an exhibition in 2020 at the Stadtgärtnerei for visitors. The exihibition is dedicated to the topic of heat mitigation and the foundation of the heat mitigation planning for the city of Zurich. The exhibition demonstrated how plants, water, shade, and the preservation of air currents help to cool the environment (Grün Stadt Zürich, 2022). In general, improvements in education and outreach can address specific barriers related to the lack of knowledge and understanding. This strategy will enable decision-makers and local communities to take action (L. Li et al., 2020). The City of Melbourne is another example. It has used e-governance Melbourne to successfully implement place-making strategies by effectively engaging citizens' knowledge in the planning process (Sarabi et al., 2019). In the case of Tempelhofer Park in Berlin, an online consultation platform was used. It involved

68,000 users and brought about 2500 idea contributors to the planning process (van Ham & Klimmek, 2017).

As education is important, interviewees said that information (E9) such as sharing knowledge from existing projects on drivers and constraints to implementation would also support the implementation of the NBS. Kabisch et al., 2016 suggested to setting up a knowledge platform or city-focused platform. These should be accessible and open to collect, pool, and co-create knowledge as an NBS stewardship community, a place that follows the principles of knowledge sharing (Bodin & Crona, 2009; Crona & Hubacek, 2010). For example, knowledge repositories such as Oppla (http://oppla.eu/) and ThinkNature (https://think-nature.eu/) or the Natural Infrastructure for Business platform (https://naturalinfrastructureforbusiness.org/) are crucial for sharing experiences and best practices in implementing NBS (Faivre et al., 2017), which in turn can encourage investment in natural infrastructure (van Ham & Klimmek, 2017). Another source to get information would be also media (L. Li et al., 2020).

2.5 Conclusion

NBS has attracted attention and are increasingly used in Zurich. Nevertheless, nature-based practices are not yet well established, which is why NBS should be necessary to address the Urban Circularity Challenges (UCC). Prior to the application of NBS, the impressions of relevant NBS stakeholders would help facilitate the successful application of NBS to address UCC. To facilitate the application of NBS in Zurich, a number of barriers to NBS implementation were identified from the perspective of four interviewees, of which (i) lack of resources, (ii) lack of knowledge, (iii) improper design, (iv) lack of communication, (v) lack of teamwork, (vi) lack of space, (vii) lengthy bureaucracy, and (viii) lack of protected areas were identified as the main barriers. One of the identifiable solutions to mitigate the impact of the barriers was the pursuit of a planned circular economy, which was recommended by the stakeholders. Good sensible and sustainable plans are important, partly due to the lack of space and resources in the city. Areas such as forests and water bodies must also be naturally preserved and protected. The results of our study also show that the implementation of NBS depends on laws. In order to increase the use of NBS in Zurich, a review of the existing laws is recommended. Other prerequisites for more NBS realisation are an intensive education system to change everyday attitudes towards NBS and providing information, models, and guides to create good NBS designs to increase trust in NBS. The implementation of NBS depends on all involved, that is, it depends on the agreement and cooperation of all, and it is between the experts, professionals, politicians, and the population. Communication between them must not be lacking.

Chapter 2: Investigation of Cooling Efficiency and Improvement of Outdoor Thermal Conditions with Nature-based Solutions in Novi Sad

3.1 Introduction

In the framework of the COST Action “Circular Cities” (CA17133) a series of short-term scientific missions (STSMs) for describing the quantification of resource streams by using nature-based solutions (NBS) was done. The goal was to provide data for a quantification model that would help select appropriate NBS to minimise resource inputs into and outputs from the city. This depends on the availability of resources as well as the processing options available to enable reuse. While at the qualitative level, there are many options for reusing resources, only a quantitative characterisation of both the required and available resources can fully support decision making for the implementation of NBS. The aim was to link them together and to conduct them in an interdisciplinary setting. (Circular cities, 2022). The following urban circular economy (UCC) topics were facilitated by specific institutions:

Table 7: Topics of the individual institutions and their acronym

Acronym	Topics of the individual institutions
UCC 1	Rainwater management and reuse (University of Ljubljana, Slovenia).
UCC 2	Wastewater generation and reuse, focusing on source separation, water quantity and treatment Aarhus University, Denmark).
UCC 3	Nutrient recovery from wastewater and source separation (Université de Paris).
UCC 4	Material and biomass recovery (alchemia-nova, Vienna, Austria)
UCC 5	Biomass and Food production (University of Córdoba – UCO, School of Agricultural and Forestry Engineering – ETSIAM, Spain).
UCC 6	Building and urban energy. (Energieinstitut an der Johannes Keppler University, Linz, Austria).
UCC6	Urban heat island and plant-related cooling effects (University of Novi Sad, Serbia).

The purpose of this chapter is to investigate the effectiveness of nature-based solutions (NBS) in improving outdoor thermal comfort (OTC) in urban cities, specifically focusing on UCC 6.

Urban form and design affect outdoor thermal comfort, by influencing air temperature, humidity, solar radiation, and wind speed and direction (Webb, 2016). Factors such as vegetation and water bodies (Lai et al., 2019), are important in determining OTC. Accordingly, the understanding of urban microclimate is imperative to facilitate climate-sensitive city planning and design (Jänicke et al., 2021). In pursuit of urban sustainability, liveability, and circularity, cities are increasingly using NBS, such as urban parks, due to their enormous potential in addressing climate adaptation and mitigation in cities (Atanasova et al., 2021; Castellar et al., 2021b; Langergraber et al., 2021; Pearlmutter et al., 2021).

In this thesis we focus on the environmental studies done in Novi Sad. This city is particularly interesting as a model city to study OTC, as it is under substantial thermal stress during extreme temperature events such as heat waves (Milošević et al., 2016). Measuring human meteorological parameters provides necessary data to understand the interactions between atmospheric processes and human health (Anderson et al., 2021). This study investigates the effect of NBS, specifically urban parks and trees in cities to improve OTC.

3.2 Materials and Methods

3.2.1 Study area

Novi Sad is an administrative, economic, cultural, scientific, and tourist centre of the Autonomous Province of Vojvodina and it is the second largest city in Serbia. The urbanized area is 112km^2 with a population of 325,000 (in 2010) (Milošević, Savić, et al., 2022). Novi Sad has *Cfb* temperature climate (Kottek et al., 2006) with the coldest month being January with −0.3 °C and the warmest being July with 21.8 °C. The mean annual precipitation is 623 mm for the period 1949–2015 (Savić et al., 2018). Novi Sad is situated on the banks of the Danube river in northern Serbia (45˚ 46` N, 19˚ 20` E) and has an average altitude of 72 to 80m (City of Novi Sad, 2011; Geletič et al., 2019). The central urban area is densely built-up consisting of medium-high buildings and low houses and buildings with little green space. Residential and industrial areas in the outskirts of the city are connected to the central city area by avenues and boulevards. The total area of green space in Novi Sad is about 7.6%. In the most built-up areas, the rate of green space is 5% and in the outskirts it is 15% (Leal Filho et al., 2021). Big green places can be found at the Danube Quay, namely the "green avenue", where the Danube is between 260 and 680 m wide. To the south of the city is the low-lying Fruška Gora hill, where a dense deciduous forest is located on a 539 m hill (Geletič et al., 2019; Savić et al., 2018). Novi Sad is classified as a complex urban form with seven built-up "local climate zones" (LCZs) according to Stewart & Oke, 2012. No additional urban parks and green spaces have been created within the city limits in the last 40 years, despite recommendations of urban planners, local authorities have not invested either in greening of buildings or greening between the blocks of buildings (Milošević, Middel, et al., 2022).

3.2.2 Calculation of Median Radiant Temperature (T_{mrt}) and Physiologically Equivalent Temperature (PET)

The Mean Radiant Temperature (T_{mrt}) and Physiologically Equivalent Temperature (PET) were selected as human-biometeorological indices, which is a branch of biometeorology concerned with the study of the effects of weather and climate on human health (Ćurić et al., 2022). The term biometeorology is sometimes used synonymously with the term "bioclimatology" as an interdisciplinary field of science that studies the effects of climate on biological processes and its consequences for living organisms (Auliciems et al., 1998). PET is defined as the air temperature at which, in a typical indoor environment (without wind or solar radiation), the thermal balance of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions being assessed. In this way, PET allows a non-specialist to compare the integral effects of complex outdoor thermal conditions with their own indoor experience. To calculate PET a programme called Rayman microclimate model was used. RayMan is a micro-scale model developed to calculate radiation fluxes in simple and complex environments. For this thesis, two-minute mean PET values were calculated with the Rayman microclimate model programme for all locations using the calculated T_{mrt} values, measured air temperature (T_a), relative humidity (*RH)*, wind velocity (*v)*, and default values for personal characteristics, and geographical locations (latitude and longitude, altitude and time zone). For personal characteristics to calculate the PET, we selected a 35-year-old man with a height of 1.75 m and a weight of 75 kg who does not perform any physical activity as our benchmark for calculation to ensure the consistency of results generated. T_{mrt} is defined as the uniform temperature of an imaginary room (or environment) in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform room (or environment) (H. Li, 2016).

In this study, T_{mrt} can be calculated with Excel from values of T_g, T_a and v as follows (Thorsson et al., 2007):

$$T_{mrt} = [(T_g + 273.15)^4 + \frac{1.1 \cdot 10^8 \cdot v^{0.6}}{\varepsilon \cdot D^{0.4}} \cdot (T_g - T_a)]^{1/4} - 273.15$$

Where:

T_{mrt} = mean radiant temperature (C°)

T_a = air temperature

T_g = globe temperature

v = wind speed (m/s)

D = globe diameter (mm)

ε = globe emissivity

Based on the research performed by Matzarakis & Mayer, 1996, the table 9 shows the translation of PET to physiological stress classes for humans in Europe.

Table 8: PET index threshold values for thermal sensation and the physiological stress level of humans (Matzarakis & Mayer, 1996).

PET (°C)	Thermal sensation	Physiological stress level
<4.1	Very cold	Extreme cold stress
4.1-8.0	Cold	Strong cold stress
8.1-13.0	Cool	Strong cold stress
13.1-18.0	Slightly cool	Slightly cool stress
18.1-23.0	Comfortable	No thermal stress
23.1-29.0	Slightly warm	Slightly heat stress
29.135.0	Warm	Moderate heat stress
35.1-41.0	Hot	Strong heat stress
> 41.0	Very hot	Extreme heat stress

3.2.3. *Field measurements*

To calculate T_{mrt} and PET, as already mentioned, the variables T_a, *RH*, *v,* T_g must be measured. The Novi Sad Urban Climate Research Team (NSUCRT) has developed Mobile Micrometeorological Carts (MMCs) which enable detailed spatial and temporal measurements in urban and non-urban areas (*Figure 7*) (Milošević, Savic, et al., 2022). MMC consists of sensors that measure those four parameters and additionally wind direction, global radiation, and six-directional short- and long-wave radiation. The measurement time resolution is two minutes, and a desktop application was created for the transfer of data from MMCs to a computer. This type of detailed and accurate equipment will enable researchers and practitioners to obtain micrometeorological data in various urban (and non-urban) areas such as urban squares, streets, parks, riverbanks, forests, etc. Measurements of climate elements in situ and or using mobile equipment on defined routes are popular approaches for assessing local and microclimatic conditions in different urban or natural areas (Popov et al., 2017, 2019) as micrometeorological data, hot and cool spots in the city can be identified. This can be used to develop climate-friendly planning and design guidelines to address heat problems in cities.

Figure 7: *Photo of the Mobile Micrometeorological Cart (MCC) 1 and 2 (by Ph.D. Dragan Milošević)*

The measurements were carried out at 25 differently designed urban locations. Those locations are divided into five different groups: (a) National Theatre Square (NTS) (reference location), (b) urban area at different locations, not under a tree (d.xtree), (c) urban area at different locations, under a tree (d.utree), (d) Danube Park at various locations not under a tree (p.xtree) and, (e) Danube Park in different locations, under a tree (p.utree) (*Figure 8).* Each group has different number of locations, therefore, each group have a different number of data (*Figure 8 and Appendix II.b*). Group (a) should represent the hottest location. This will be compared with the rest of the groups to analyse if there are different OTC. MCC1 measured for group a) during the whole day (8-19:30h). MCC 2 was driven along a fixed route to measure the microclimate from each location. Therefore, MCC2 was stopped for 2 to 3 minutes to take the measurements (*Figure 8).* This was conducted in four specific periods of the day: morning (8-9:00h local time), midday (11-12:00h), afternoon (15-16:00h), and evening (18-19:30h). In some cases, it was possible to plan the circumstances of the measurements (sun and shade), but in other cases, for example, in certain weather conditions, this was not possible (shade, mixed shade, and cloudy weather). All measurements with MCC2 were noted for this, except with MCC1. For MCC1 situated at the National Theatre Square, it was assumed that the measurements would take place in the sun throughout the day.

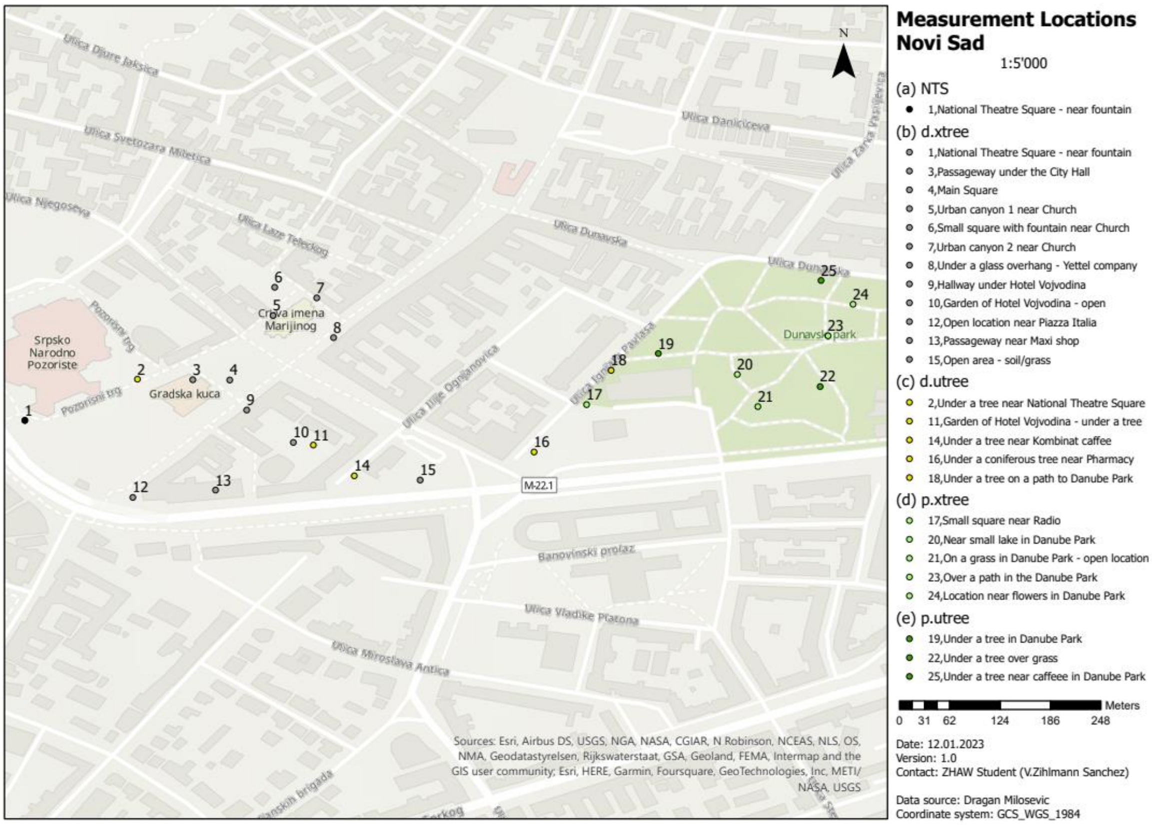


Figure 8: Measurement locations in Novi Sad, Serbia. Measurement location of group (a) NTS (location 1; black dot), measurement location of group (b) d.xtree (location 1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 15; grey dot), measurement location of group (c) d.utree (location 2, 11, 14, 16, 18; yellow dot), measurement location of group (d) p.xtree (location 17, 20, 21, 23, 24; light green dot), measurement location of group (e) p.utree (location 19, 22, 25; dark green dot).

After the measurements, the data was put into Excel to calculate T_{mrt}. With the Rayman programme PET was calculated with the measurements T_a, v, RH and with the calculated T_{mrt}. Solar radiation (*Sr*) and the factors if it were in the sun, shade, etc. were also considered. In the next step, the measured values from each location were sorted into their groups. Then the values of group (a) were compared with the values of the other groups. In this analysis, it was particularly important to compare the data with the correct measurement times. In addition, for the result, the physiological stress level was quantified in frequencies.

3.3 Results

3.3.1 Background weather

In the summer of 2022 (from 1 June to 31 August), the mean seasonal *Ta* in the Serbian lowlands ranged between 21°C and 24°C, which was above average and an anomaly of up to +2°C in Serbia. Seasonal rainfall totals in northern Serbia ranged from 120 mm to 240 mm, and the number of rainy days (x ≥ 0.1 mm) ranged from 18 to 28 days. This indicates a warm and dry summer (Republic Hydrometeorological Service & Republic of Serbia, 2022).

3.3.2 Air Temperature

The table 11 and figure 9 describe the results of an air temperature study conducted in Novi Sad. The highest maximum and minimum temperatures were also recorded in these groups, with 0.1°C differences. T_a was recorded in downtown urbanized locations, with a temperature of 30.7°C. The urbanized locations had the largest temperature range of 9.4°C compared to the park locations, which had a range of 8.3°C. The highest standard deviation was recorded at the National Theatre Square near the fountain, with a value of 3.35°C. The rest of the urbanized groups had similar values around 3°C. Figure 9 shows temporal variability of T_a in Novi Sad, with small intra-urban differences between hotter locations in the urban center and cooler locations in the urban parks, especially in the morning and evening.

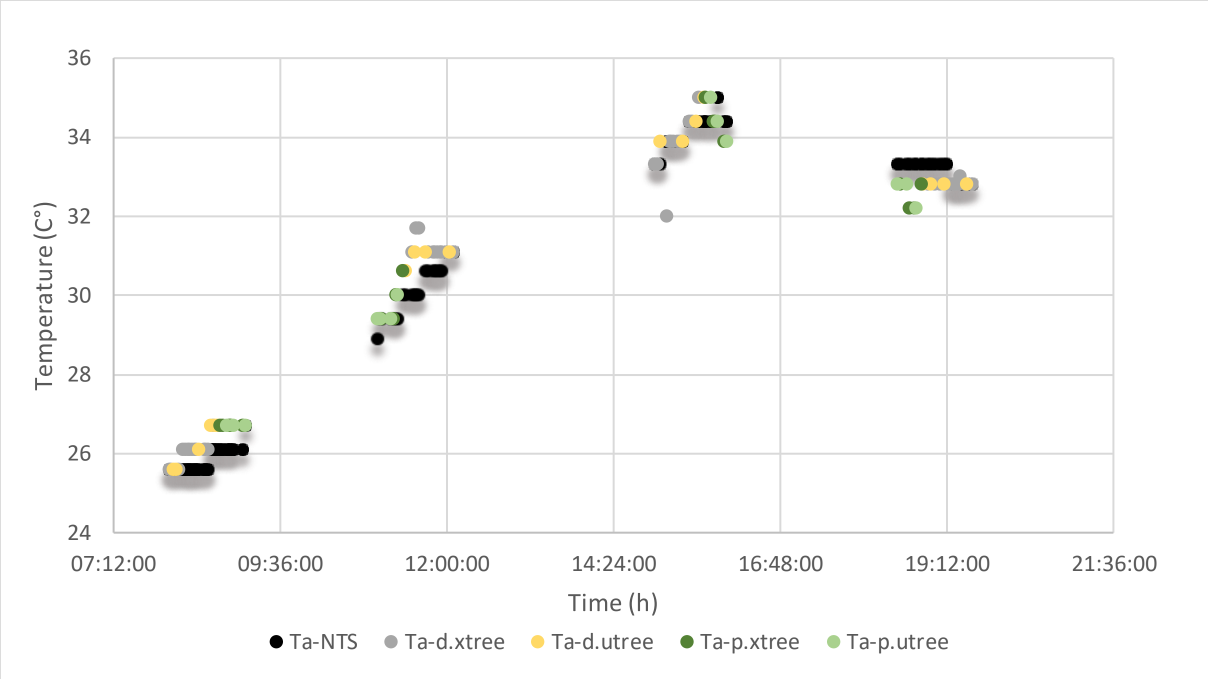


Figure 9: Temporal variation of T_a in Novi Sad, Serbia in the period 17 August 2022 (measurement periods 08-09:00h, 11-12:00h, 15-16:00h, and 18-19:00h CEST). NOTE: T_a-NTS represents air temperature from group (a) National Theatre Square, T_a-d.xtree represents air temperature from group (b) urban area locations without trees, T_a-d.utree represents air temperature from group (c) urban area locations with trees, T_a-p.xtree represents air temperature from group (d) urban park locations without trees and, T_a-p.utree represents air temperature from group (e) urban park locations with trees.

3.3.3 Relative Humidity

The highest average *RH* values are observed in the Danube Park (42.3%), followed by the group urban areas under a tree (41.9%). In contrast, the lowest average *RH* was noticed at the National Theatre Square, near the fountain (40.9%). The highest maximum (57%) and minimum (29%) *RH* values are registered at the National Theatre Square and urban and park locations not under a tree. The larger range and standard deviation of RH are from the National Theatre Square (*Table 11*).

Temporal variation of *RH* shows some differences between the locations during the period 8-9h, 11-12h, 15-16h and 18.30-19h (*Figure10*). For example, except in the morning, where *RH* values are the highest (54-57%), the measurements from the Danube parks are mostly above the values from the urban areas. In the morning and midday hours, the *RH* values decrease at all locations until the afternoon (15-16:00h). However, the first groups where *RH* values increase are the locations in the parks. In the evening (18:30-19:30), the *RH* also starts to increase in the urban areas.

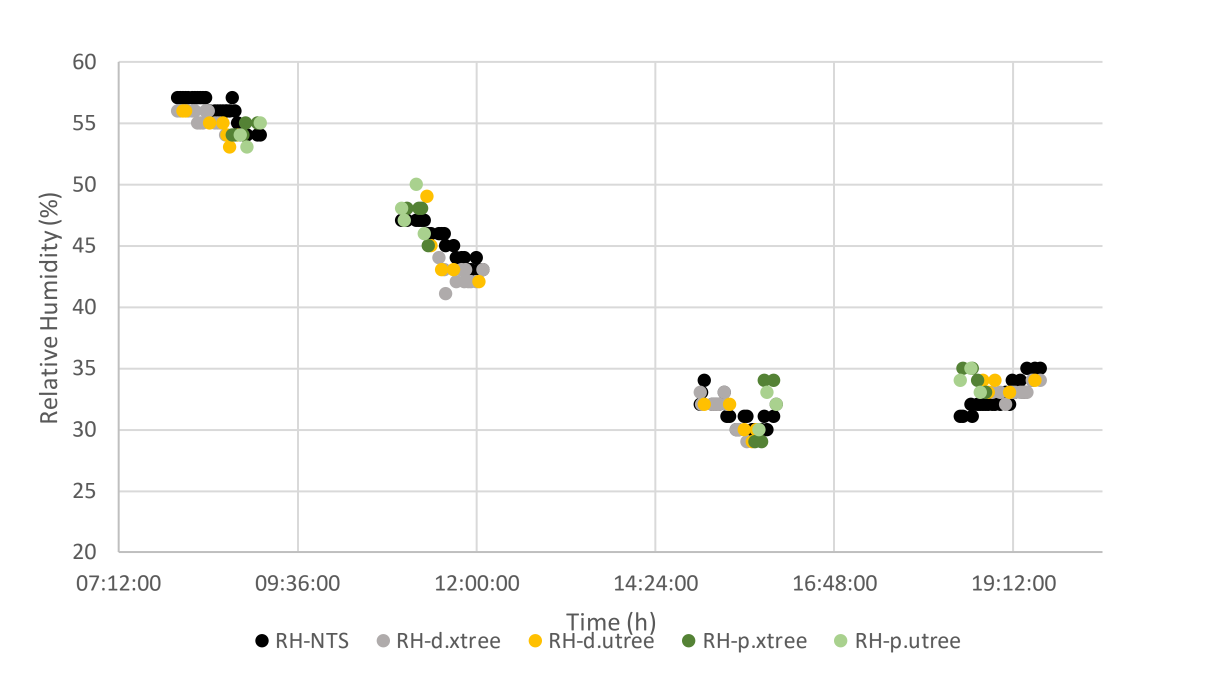


Figure 10: Temporal variation of RH in Novi Sad, Serbia in the period 17 August 2022 (measurement periods 08-09:00h, 11-12:00h, 15-16:00h, and 18-19:00h CEST). NOTE: RH-NTS represents relative humidity from group (a) National Theatre Square, RH-d.xtree represents relative humidity from group (b) urban area locations without trees, RH-d.utree represents relative humidity from group (c) urban area locations with trees, RH-p.xtree represents relative humidity from group (d) urban park locations without trees and, RH-p.utree represents relative humidity from group (e) urban park locations with trees.

3.3.4 Wind Speed

During the measurement periods, the lowest *v* average value was at the locations in Danube Park (0.7 m/s) under a tree and the highest *v* average value was in at the urban area's locations under a tree (1.2 m/s). The highest maximum (2.6 m/s) and minimum (0 m/s) *v* values are at the National Theatre Square, thus leading to larger range and standard deviation of *v* at this location. The lowest range and standard deviation are in the Danube Park (*Table 11*).

3.3.7 Solar Radiation

The highest average *Sr* value is in Danube Park without trees (328.76 W/m^2) and the lowest average *Sr* value is also in Danube Park but under trees (155.8 W/m^2). The other groups have an average *Sr* value between 223 and 226 W/m^2. The minimum *Sr* was measured in the urban area in the passage near the Maxi Shop at 19:02h in the shade and at 19:28h in the shade in the passage under the City Hall (*Table 11 and Appendix II.b*).

Figure 11 shows the frequency of measurements in sun, shade, mixed shade and cloudy weather. Three of the groups were most frequently measured in shade, namely in urban areas under trees (56.86 %), in the Danube Park and in urban areas under trees (64.7 %). That is, measurements with MCC2 at the urban locations were less than 50% in the sun. The measurement frequency in Danube Park in locations not under a tree, were only 17.6% in the shade. When measuring in Danube Park under a tree, MCC2 was either in full shade (63%) or it was in mixed shade (29%) (*Appendix x and Figure 11*).

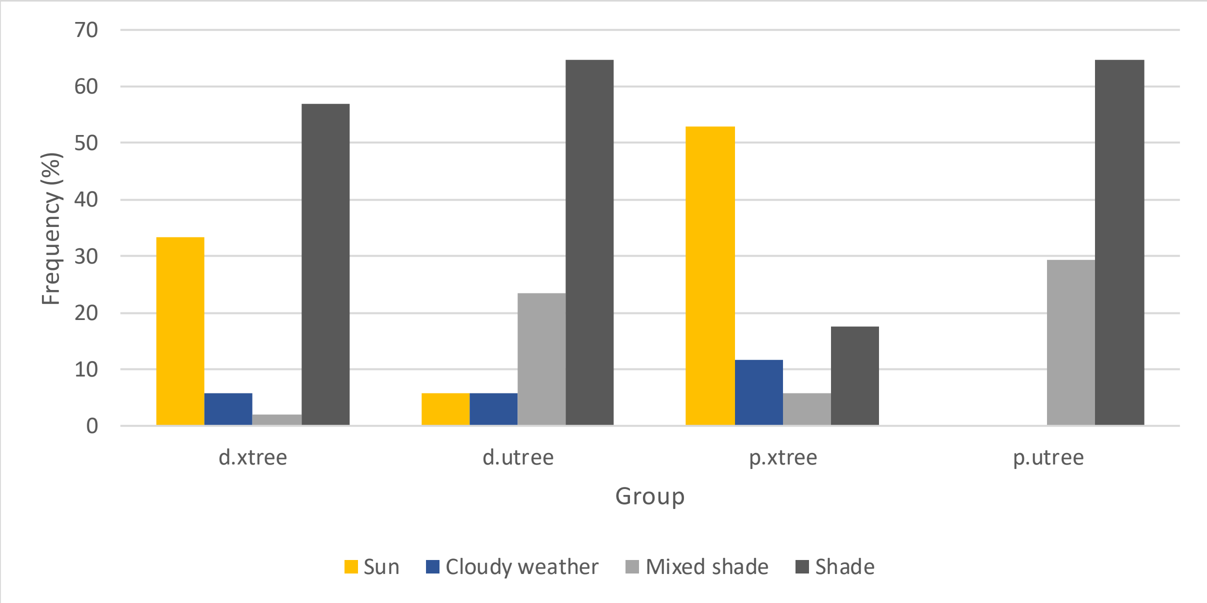


Figure 11: Frequency analysis (%) of sun, shade, mixed shade and, cloudy weather during measurements of group (b) locations in the urban area without trees, group (c) locations in the urban area with trees, group (d) locations in the urban park without trees and group (e) locations in the urban park with trees at sites in Novi Sad in the period 07 August 2022 (measurement periods 08-09:00h, 11-12:00h, 15-16:00h and 18-19:00h CEST).

3.3.6 Globe Temperature

The highest T_g values were measured in the National Theatre Square (38°C), with 2-2.5°C higher T_g values compared to the other groups (*Table 11*). The highest T_g values were also measured at 15:12h in the National Theatre Square (58.5°C). Comparing group (a) with the other groups, their maximums are 10°C cooler. The minimum was in the city area (25.5°C) under the tree on National Theatre Square at 08:06 (*Table 11 and Appendix II a*). The highest minimum with a difference of 4.5°C was measured in the Danube Park under a tree, followed by measurements in the Danube Park without a tree and the measurements on the National Theatre Square with a difference of 2.2°C. The largest range is found at National Theatre Square and also has the highest standard deviation. The lowest standard deviation is found in the group Danube Park without tree.

The measurement periods 8-9h, 11-12h, 15-16h, and 18.30-19h at different locations provide detailed insights into the temporal variability of globe temperature in Novi Sad (*Figure 12)*. The lowest readings of all groups are in the morning and increase until the afternoon. During both the morning and noon measurement periods, the T_g values in the urban areas, with the exception of NTS, are higher than those of the other groups. At noon (11-12:00h) the readings at National Theatre Square are the lowest of all groups. This changes in the afternoon (15-16:00h), when the T_g values measured at National Theatre Square are the highest, mostly between 50 and 60°C. The other T_g values of the other groups are about the same, between 38 and 48°C. In the evening (18-19:30h), all T_g values from each group decrease between 32 and 40°C. Nevertheless, the National Theatre Square T_g values are higher than those of the other groups.

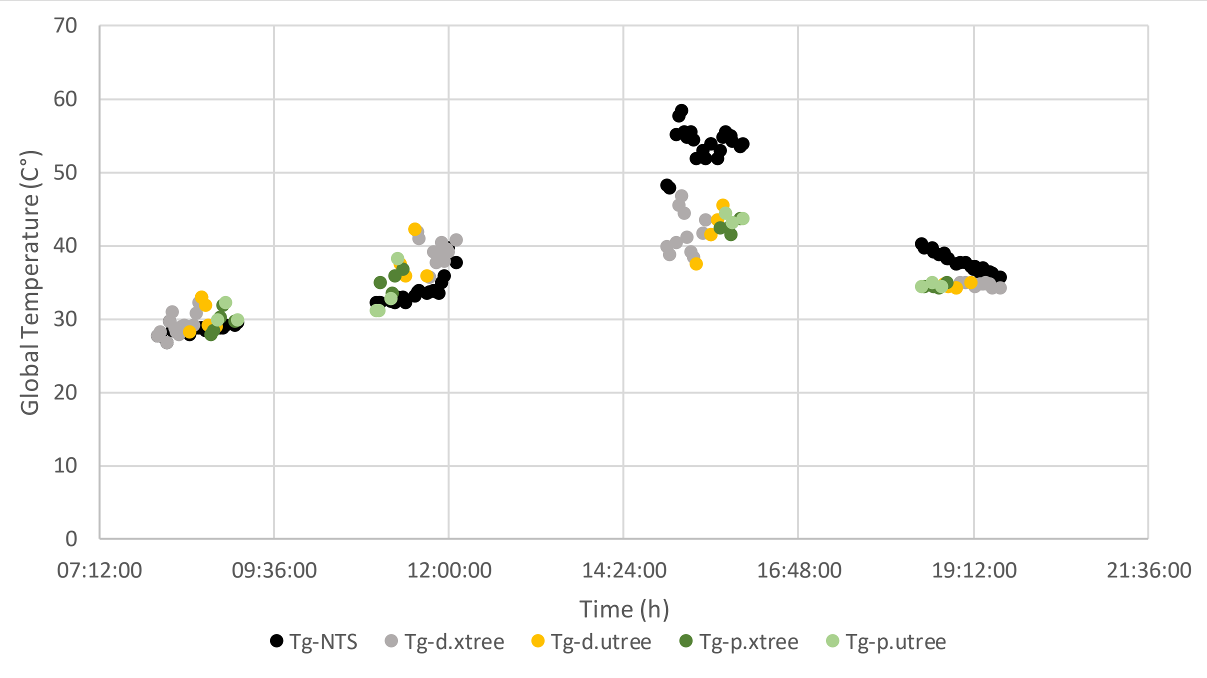


Figure 12: Temporal variation of T_g in Novi Sad, Serbia in the period 17 August r 2022 (measurement periods 08-09:00h, 11-12:00h, 15-16:00h, and 18-19:00h CEST). NOTE: T_a-NTS represents globel temperature from group (a) National Theatre Square, T_g-d.xtree represents globe temperature from group (b) urban area locations without trees, T_g-d.utree represents air temperature from group (c) urban area locations with trees, T_g-p.xtree represents globe temperature from group (d) urban park locations without trees and, T_g-p.utree represents globe temperature from group (e) urban park locations with trees.

3.3.7 Mean Radiant Temperature

The National Theatre Square had the highest average T_{mrt} of 50.3°C, followed by the grouop urban area not under a tree with 46.6°C. In contrast, the urban park has a much lower average T_{mrt} of 43.4°C, which is 7°C lower than NTS. The highest minimum T_{mrt} value was recorded at NTS at 08:06h under a tree in the National Theatre Square (*Table 11 and Appendix II.a*). NTS also has the highest range and standard deviation. Compared to the urban park groups, the maximum T_{mrt} value did not exceed 60.5°C (*Table 11 and Figure 13*). The Danube Park under a tree group had a T_{mrt} minimum of 33.6°, 3°C warmer than the minimum of NTS and it was measured in Donaupark under a tree near the Danube Park café at 11:02h.

The temporal variation of the T_{mrt} values shows that the National Theatre Square has significantly higher Tmrt values during the day compared to other urban areas (with and without trees) and the urban park (with and without trees) (*Figure 13*). In the morning, all have approximately the same T_{mrt} value. Over midday, the values around the urban areas increase more than the T_{mrt} values from the Danube parks. In the afternoon, the highest T_{mrt} values reach the group National Theatre Square, followed by the group of urban areas without trees, then urban areas with trees and finally the groups of the urban parks. In the afternoon, all T_{mrt} values decrease, however, the T_{mrt} value the National Theatre Square decrease later.

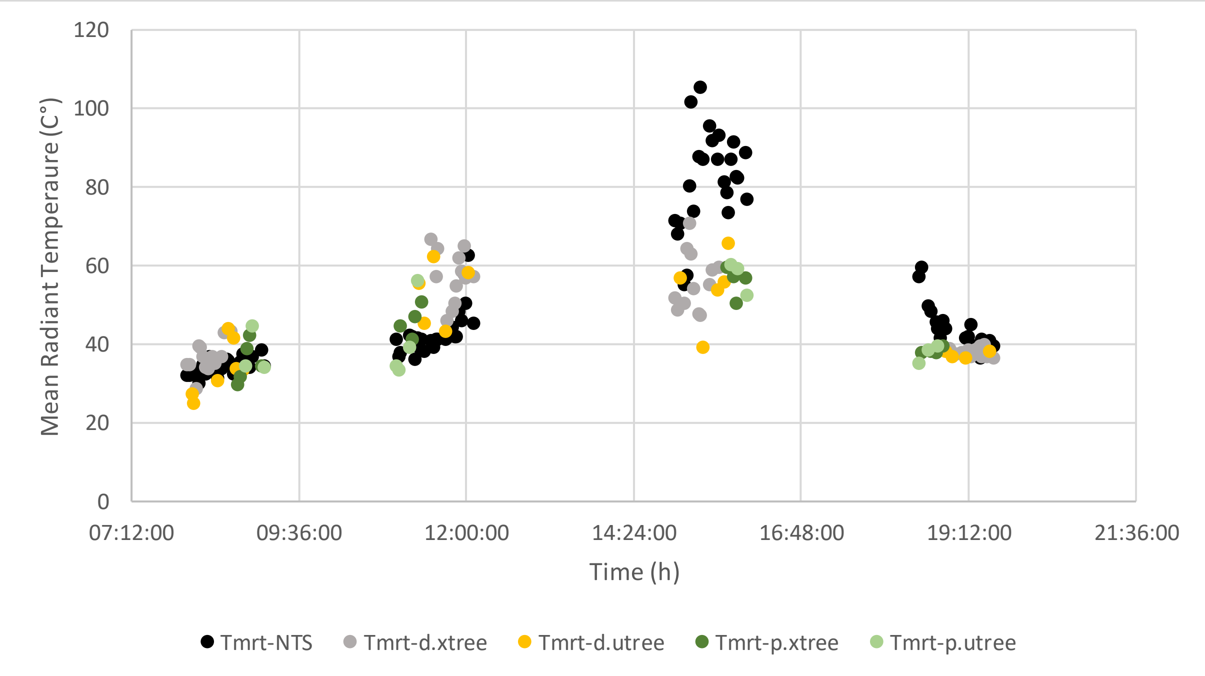


Figure 13: Temporal variation of T_{mrt} in Novi Sad, Serbia in the period 17 August 2022 (measurement periods 08-09:00h, 11-12:00h, 15-16:00h, and 18-19:00h CEST). NOTE: T_{mrt}-NTS represents Median Radiant Temperature from group (a) National Theatre Square, T_{mrt}-d.xtree represents Mean Radiant Temperature from group (b) urban area locations without trees, T_{mrt}-d.utree represents Mean Radiant Temperature from group (c) urban area locations with trees, T_{mrt}-p.xtree represents Mean Radiant Temperature from group (d) urban park locations without trees and, T_{mrt}-p.utree represents Mean Radiant Temperature from group (e) urban park locations with trees.

3.3.8 Physiologically Equivalent Temperature

The highest average PET value was registered at the National Theatre Square (38.9°) (*Table 11*). The other locations had a 1-2°C lower average PET value. This indicates that each location was under extreme heat stress (*Table 9*). The temporal variation of PET showed similar results to T_{mrt} (*Figures 13 and 14*). In other words, during the period 15-16:00, the National Theatre Square has much higher values than the other groups. Therefore, highest PET maximum value is reached in the National Theatre Square in the afternoon (64.6°C). Compared to the PET values of the Danube Park, the maximum values are about 9°C cooler. The PET minimum is in the morning between 08:04h and 08:06h in an urban area under a tree near the National Theatre Square (23°C) (*Table 11 and Appendix II.a*). The highest range and standard deviation are at the National Theatre Square, the lowest in the Danube Parks.

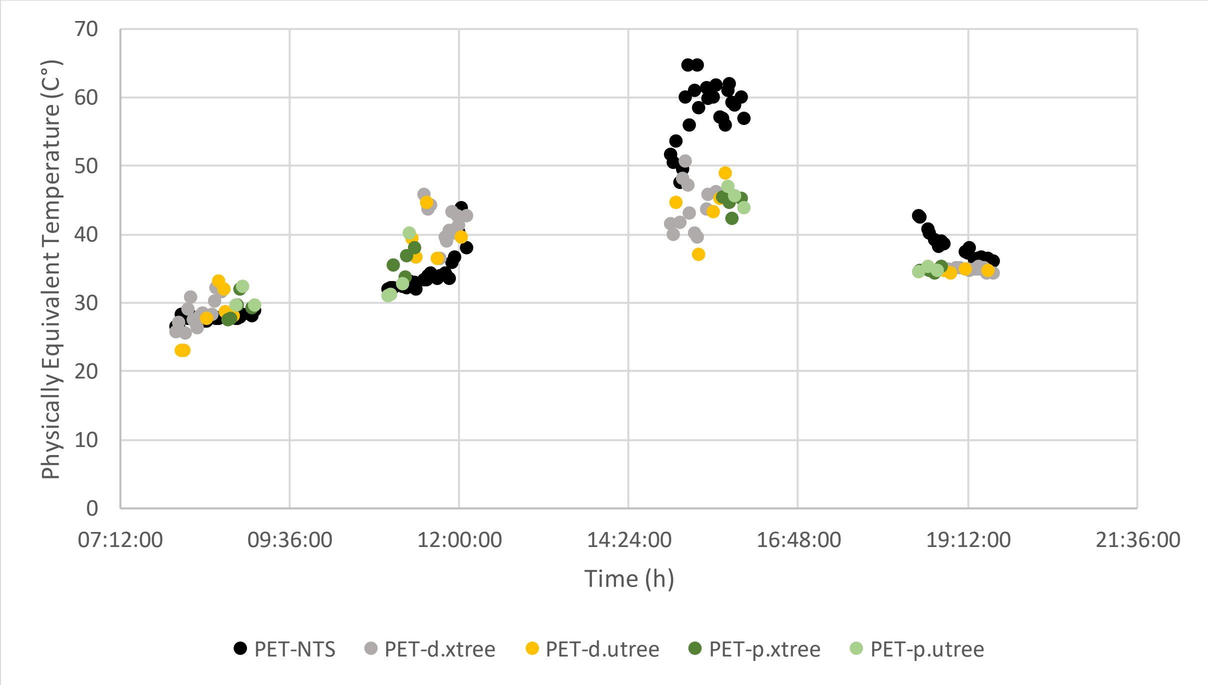


Figure 14: Temporal variation of PET in Novi Sad, Serbia in the period 17 August 2022 (measurement periods 08-09:00h, 11-12:00h, 15-16:00h, and 18-19:00h CEST). NOTE: PET-NTS represents Physiologically Equivalent Temperature from group (a) National Theatre Square, PET-d.xtree represents Physiologically Equivalent Temperature from group (b) urban area locations without trees, PET-d.utree represents Physiologically Equivalent Temperature from the group (c) urban area locations with trees, PET-p.xtree represents Physiologically Equivalent Temperature from group (d) urban park locations without trees and, PET-p.utree represents Physiologically Equivalent Temperature from group (e) urban park locations with trees.

Most extreme stress conditions compared to the other group are in urban areas not under trees, flowed by National Theatre Square (30%). Except for the locations in Danube Park under the tree with 15% frequency, the rest had a frequency of strong heat stress conditions of around 20% (*Figure 15*). The highest frequency of moderate heat stress conditions is in the Danube Park under a tree (61%), followed by Danube Park not under a tree (41%), then urban areas under a tree (31%), urban areas not under a tree (25%) and at least National Theatre Square (19%). The most frequent slightly heat stress condition is in National Theatre Square (30%). Except group Danube Park under a tree with 15% frequency, the others have between 21 and 23% frequency. No thermal stress condition happened in a frequency of 9% in the urban areas under the trees.

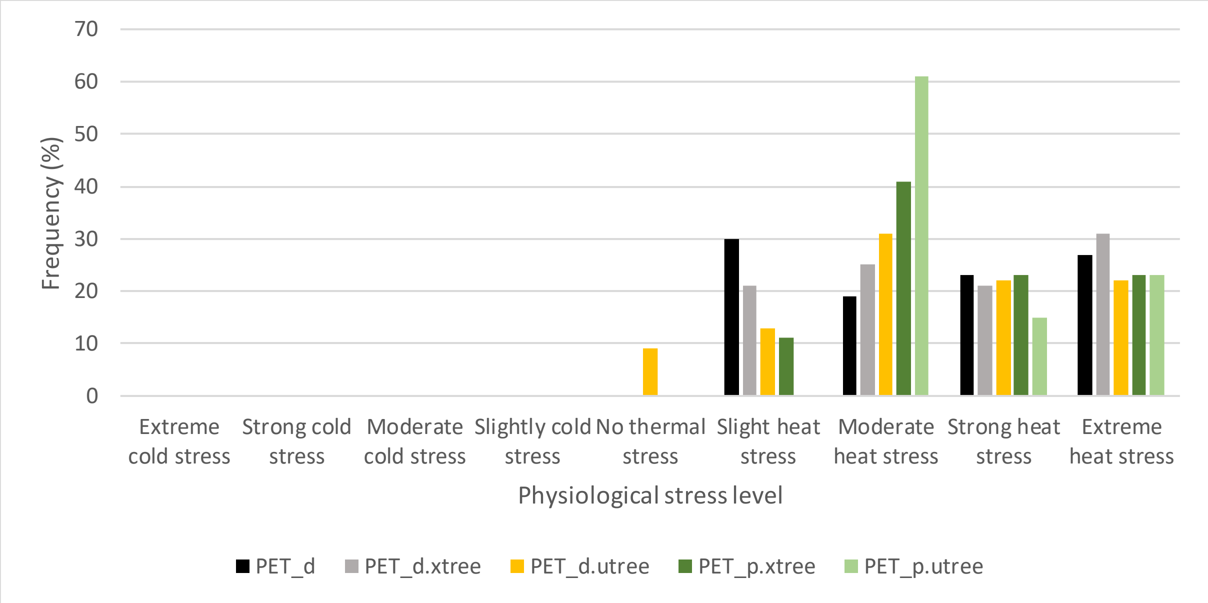


Figure 15: Frequency analysis (%) of different grades of physiological stress (based on PET values) at locations in Novi Sad in period 07 August 2022 (measurements periods 08-09:00h, 11-12:00h, 15-16:00h, and 18-19:00h CEST)

Table 9: Main statistical characteristics of air temperature (T_a), relative humidity (RH), wind speed (v), globe temperature (T_g), solar radiation (Sr), Mean Radiant Temperature (T_{mrt}), Physiologically Equivalent Temperature (PET) in diverse groupe environment.

Element	T_a (C°)					RH (%)				
Group	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**
Average	30.5	30.7	30.7	30.6	30.7	42.09	41.5	41.9	42.3	42.3
Max	35	35	35	35	35	57	56	56	55	55
Min	25.6	25.6	25.6	26.7	26.7	29	29	30	29	30
Range	9.4	9.4	9.4	8.3	8.3	28	27	26	26	25
St Dev	3.35	3.22	3.3	3.1	2.9	10.5	9.9	10.3	10.1	9.5
Element	v (m/s)					T_g (C°)				
Group	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**
Average	0.97	1.1	1.2	0.8	0.7	38	35.9	35.4	35.1	35.5
Max	2.6	2.4	2.5	1.5	1.3	58.5	46.7	45.5	43.7	44.5
Min	0	0.4	0.7	0.5	0.1	27.7	26.7	25.5	28	30
Range	2.6	2	1.8	1	1.2	30.7	20	20	15.7	14.5
St Dev	0.57	0.4	0.5	0.3	0.4	9.6	5.4	5.8	4.9	5.3
Element	Sr (W/m2)					T_{mrt} (C°)				
Group	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**
Average	258.6	222.6	223.5	328.8	155.8	50.3	46.6	45.0	43.6	43.4
Max	747	784	761	770	791	105.5	70.9	65.9	59.8	60.5
Min	3	0	5	15	3	30	28.9	25.2	29.9	33.6
Range	744	784	756	755	788	75.4	42.08	40.6	29.9	26.9
St Dev	293.0	285.4	306.5	321.9	260	20.1	10.9	12.1	8.9	10.2
Element	PET (C°)									
Group	**NTS**	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**					
Average	38.9	36.7	35.9	35.6	35.9					
Max	64.6	50.6	48.9	45.4	46.9					
Min	26.6	25.6	23	27.4	29.6					
Range	38	25	25.9	18	17.3					
St Dev	11.8	6.7	7.4	5.8	6.13					

3.4 Discussion

3.4.1 Cooling Effect

In the present study, the cooling effect of seven parameters in certain urban areas (with and without trees) and urban parks (urban parks with and without trees) was investigated as NBS. However, the data sets and measurements of the different groups were partly different, which might have influenced the data. A solid foundation is important to gain descriptive and inferential statistical insights (Unity College, 2017).

In the morning urban area, T_a is cooler than in the park (*Figure 9*). This could be the consequences of the shadowing effect from buildings surrounding at the measurement's location, as temperature differences are related to shading (Morakinyo et al., 2017). Thus, it also explains the lack of difference seen between the urban areas with (d.utree) and without trees (d.xtree), as d.xtree was mainly in the shade (*Figure 11*). For example, in the paper Klok et al., 2019 results clearly demonstrate that the thermal effect of shading is the largest. Their measurements have particularly show that shading by buildings or trees has the largest cooling effect on the urban environment, without clear difference in shading by buildings or trees. This can be also in this study threw the low *Sr (Table 11)* and T_a values (*Figure 9)*. By the afternoon, all groups rise to the maximum temperature of 35°C. Unlike this study, previous studies have shown that the highest temperatures are usually found in more urbanised areas of the city. For example, Oliveira et al., 2021 showed that the highest temperatures were in more compact areas of Lisboa, Portugal and that these temperatures were proportional to the change in background T_a. The T_a values of the groups in the urban park are the first to decrease (*Figure 9*). In general, T_a decrease in the afternoon due the shading effect and less intensive heating in the afternoon hours between 17-18:00h (Milošević, Savić, et al., 2022). The urban area needs more time to cool down because urban materials such as concrete and pavement absorb solar energy during the day. They slowly release this energy into the air, especially at night, in the form of heat (Heaviside et al., 2017). In other words, heat waves with hot weather in cities with urban materials are particularly characterised by strong night-time urban heat island (UHI) (Hathway & Sharples, 2012). However, Urban green spaces such as street trees and green parks, can also provide cooler outdoor conditions through evapotranspiration during night-time (Aboelata & Sodoudi, 2020). This is because plants release water through transpiration and respiration at night, leading to an increase in the environment's humidity (Feng et al., 2022). A study has shown, that lower humidity and urban dry island in Novi Sad, Serbia often occurs in densely urbanized areas in summer daytime and during heat wave (Dunjić et al., 2021). In this study, in the morning and in the evening, *RH* in the urban park are higher compared to the urban areas (*Figure 10*). This means, increasing vegetation density can provide evapotranspiration, which can reduce human heat stress in urban areas (L. Kong et al., 2017). Zhang et al., 2014 pointed out that urban green spaces generally can cool the environment, however their cooling potential differs depending on the green space's structure and size. Also, heat reduction potential of trees depends on the location of trees and its species (de Abreu-Harbich et al., 2015). In terms of wind speed difference between urban areas and city parks could be due to the open spaces. For example, the air movement in an urban canyon is higher than in a less open place, such as an urban park (Geletič et al., 2019). Therefore, this could be a reason why in this study the average wind speed was a little higher in the urban areas than in the parks (*Table 11*).

3.4.2 Outdoor Thermal Comfort

In the period 15-16:00h, NTS and urban areas without trees location become the most thermally uncomfortable part of the city (*Figure 15*). This is possibly a consequence of direct solar radiation direct and from the surrounding such as buildings (Erell et al., 2014), the absorbed heat from the concrete and asphalt during the day (Bergamin, 2017) and, the missing humidity (Rahman et al., 2015). Similar to our results, higher PET levels were found in urban areas compared to sparsely built-up and densely forested areas in Oberhausen, Germany, and in Ghent, Belgium, during the daytime heatwave period (Geletič et al., 2019; Müller et al., 2014). In this work, in Novi Sad, the groups Danube Park under trees reached the physiological stress level frequency of moderate heat stress by 60% and without trees by 40%. This is more than in urban areas and confirms the cooling effect of NBS. This also was confirmed in a study in Czech cities in which substantial cooling was associated with high vegetation (trees), while the measurable cooling effect of low vegetation was negligible and quite low around water fountains, spray fountains, and misting systems (Lehnert et al., 2021). However, the NTS show for Sightly heat stress a PET frequency of 30%. This contradicts the other studies that have been mentioned. This could be due to the fact that MCC1 started measuring earlier and later than the other groups and also continuously, which led to more data and also to a misinterpretation of the data (Appendix). Furthermore, d.xtree did not show a high frequency of extreme heat stress as expected, as it mostly stayed in the shade (*Figure 11*).

The maximum of T_{mrt} on the NTS shows a very high value (*Table 11*), which could indicate a measurement error due to increasing wind speed and heating of the sensor by solar radiation (Huwald et al., 2009). Most standard temperature measurements are subject to significant errors, mainly due to heating of the sensor by solar radiation, even if the measurement principle is accurate and precise. This may have been the case for MCC1 in the afternoon when it was next to a fountain, which has a strong albedo effect, and the wind speed rose above 2 m/s (*Appendix II a).* However, further investigations need to be carried out.

3.5 Conclusion

Our study investigated OTC conditions in Novi Sad and show the importance of small-scale micrometeorological measurements for climate-smart urban design. It also confirms the frequency of feeling extreme heat stress in unshaded urban areas is higher than locations in urban areas with shading or and more in urban parks (with shading). This suggests that NBS can have a cooling effect in urbanised cities. However, detailed spatial and temporal climate data for the urban planning process and practice are lacking. For example, this study should have considered for comparison the availability of the same amount of data from all groups. Also, it would have been interesting to measure different types of NBS to determine the different cooling efficiency. Despite everything, this kind of research based on field measurements of extreme heat can provide local authorities with detailed temporal and spatial climate information and guide their efforts to mitigate extreme heat in the right place and at the right time.

5. Acknowledgements

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6. Literature

Abbott, J., Davies, P., Simkins, P., Morgan, C., Levin, D., & Robinson, P. (2013). *Creating water sensitive places—Scoping the potential for Water Sensitive Urban Design in the UK* (Ciria, Ed.). https://www.ciria.org/CIRIA/CIRIA/Item_Detail.aspx?iProductCode=C724F&Category=FREEPUBS

Aboelata, A. (2021). Reducing outdoor air temperature, improving thermal comfort, and saving buildings' cooling energy demand in arid cities – Cool paving utilization. *Sustainable Cities and Society*, *68*, 102762. https://doi.org/10.1016/j.scs.2021.102762

Aboelata, A., & Sodoudi, S. (2020). Evaluating the effect of trees on UHI mitigation and reduction of energy usage in different built up areas in Cairo. *Building and Environment*, *168*, 106490. https://doi.org/10.1016/j.buildenv.2019.106490

Amberscript. (2021, April 7). *Konvertieren Sie Audio und Video automatisch zu Text*. Amberscript. https://www.amberscript.com/de/

Anderson, V., Leung, A. C. W., Mehdipoor, H., Jänicke, B., Milošević, D., Oliveira, A., Manavvi, S., Kabano, P., Dzyuban, Y., Aguilar, R., Agan, P. N., Kunda, J. J., Garcia-Chapeton, G., de França Carvalho Fonsêca, V., Nascimento, S. T., & Zurita-Milla, R. (2021). Technological opportunities for sensing of the health effects of weather and climate change: A state-of-the-art-review. *International Journal of Biometeorology*, *65*(6), 779–803. https://doi.org/10.1007/s00484-020-02063-z

Andersson, E., Borgström, S., & McPhearson, T. (2017). *Double Insurance in Dealing with Extremes: Ecological and Social Factors for Making Nature-Based Solutions Last* (N. Kabisch, H. Korn, J. Stadler, & A. Bonn, Eds.; pp. 51–64). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_4

Armson, D., Stringer, P., & Ennos, A. R. (2013). The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. *Urban Forestry & Urban Greening*, *12*(3), 282–286. https://doi.org/10.1016/j.ufug.2013.04.001

Artmann, M., & Breuste, J. (2015). Cities Built for and by Residents: Soil Sealing Management in the Eyes of Urban Dwellers in Germany. *Journal of Urban Planning and Development*, *141*, A5014004. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000252

Atanasova, N., Castellar, J. A. C., Pineda-Martos, R., Nika, C. E., Katsou, E., Istenič, D., Pucher, B., Andreucci, M. B., & Langergraber, G. (2021). Nature-Based Solutions and

Circularity in Cities. *Circular Economy and Sustainability*, *1*(1), 319–332. https://doi.org/10.1007/s43615-021-00024-1

Auliciems, A., Dear, R. de, Fagence, M., Kalkstein, L. S., Kevan, S., Szokolay, S. V., & Webb, A. R. (1998). *Advances in bioclimatology. Vol. 5. Human bioclimatology*. ETDEWEB. https://www.osti.gov/etdeweb/biblio/621903

Bah, M., Chapman, E., & Gäckle, J. (2021). *Stakeholder mapping report in each of the Cultivating Cities* (GoGreenRoutes, Ed.). https://gogreenroutes.eu/publication?t=Stakeholder%20mapping%20report%20in%20each%20of%20the%20Cultivating%20Cities

Balzan, M. V., Geneletti, D., Grace, M., De Santis, L., Tomaskinova, J., Reddington, H., Sapundzhieva, A., Dicks, L. V., & Collier, M. (2022). Assessing nature-based solutions uptake in a Mediterranean climate: Insights from the case-study of Malta. *Nature-Based Solutions*, *2*, 100029. https://doi.org/10.1016/j.nbsj.2022.100029

Baumann, J. (Director). (2022, August 2). *Klimawandel macht Naturkatastrophen immer teurer—Rendez-vous—SRF*. https://www.srf.ch/audio/rendez-vous/klimawandel-macht-naturkatastrophen-immer-teurer?partId=12231397

Beceiro, P., Brito, R. S., & Galvão, A. (2022). Assessment of the contribution of Nature-Based Solutions (NBS) to urban resilience: Application to the case study of Porto. *Ecological Engineering*, *175*, 106489. https://doi.org/10.1016/j.ecoleng.2021.106489

Bennett, E. M., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B. N., Geijzendorffer, I. R., Krug, C. B., Lavorel, S., Lazos, E., Lebel, L., Martín-López, B., Meyfroidt, P., Mooney, H. A., Nel, J. L., Pascual, U., Payet, K., Harguindeguy, N. P., Peterson, G. D., … Woodward, G. (2015). Linking biodiversity, ecosystem services, and human well-being: Three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability*, *14*, 76–85. https://doi.org/10.1016/j.cosust.2015.03.007

Bergamin, F. (2017, July 21). *«Asphalt hat einen gewichtigen Nachteil»*. https://ethz.ch/de/news-und-veranstaltungen/eth-news/news/2017/07/hitzewelle-in-der-stadt.html

BK, B. (2022, November 7). *Der Bund kurz erklärt*. https://www.bk.admin.ch/bk/de/home/dokumentation/der-bund-kurz-erklaert.html

Blakelock, C., & Maynes, C. (2017). *NEW! Stormwater Scorecard.*

Bodin, Ö., & Crona, B. I. (2009). The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change*, *19*(3), 366–374. https://doi.org/10.1016/j.gloenvcha.2009.05.002

Bonderer, D., Maag, T., Weber, K., & Pfanner, M. (2017, June 20). *Schwemmholzrechen verbessert den Hochwasserschutz an der Sihl*. Kanton Zürich. https://www.zh.ch/de/news-uebersicht/medienmitteilungen/2017/06/schwemmholzrechen-verbessert-den-hochwasserschutz-an-der-sihl.html

Borsje, B. W., Van Wesenbeeck, B., Dekker, F., Paalvast, P., Bouma, T., Katwijk, M., & de Vries, M. (2011). How ecological engineering can serve in coastal protection. *Ecological Engineering*, *37*, 113–122. https://doi.org/10.1016/j.ecoleng.2010.11.027

Bouwma, I., Schleyer, C., Primmer, E., Winkler, K. J., Berry, P., Young, J., Carmen, E., Špulerová, J., Bezák, P., Preda, E., & Vadineanu, A. (2018). Adoption of the ecosystem services concept in EU policies. *Ecosystem Services*, *29*, 213–222. https://doi.org/10.1016/j.ecoser.2017.02.014

Brenner, M. (2016, November 10). *Wem gehört Zürich? - Stadt Zürich*. https://www.stadt-zuerich.ch/prd/de/index/statistik/publikationen-angebote/publikationen/webartikel/2016-11-10_Wem-gehoert-Zurich.html

Briney, A. (2018, August 20). *10 Facts About the Geography of Reykjavik, Iceland*. ThoughtCo. https://www.thoughtco.com/geography-of-reykjavik-iceland-1435042

Brown, R., & Farrelly, M. (2008, August 22). *Sustainable Urban Stormwater Management in Australia: Professional Perceptions on Institutional Drivers and Barriers*.

Brown, R. R., & Farrelly, M. A. (2009). Challenges ahead: Social and institutional factors influencing sustainable urban stormwater management in Australia. *Water Science and Technology*, *59*(4), 653–660. https://doi.org/10.2166/wst.2009.022

Burri, S. (2015, February 19). Schweiz—«Weg mit der Bürokratie!» – leichter gesagt, als getan. *Schweizer Radio und Fernsehen (SRF)*. https://www.srf.ch/news/schweiz/weg-mit-der-buerokratie-leichter-gesagt-als-getan

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities*, *95*, 102483. https://doi.org/10.1016/j.cities.2019.102483

Business For Nature. (2022). *Advocate*. Business For Nature. https://www.businessfornature.org/advocate

Calfapietra, C., Peñuelas, J., & Niinemets, Ü. (2015). Urban plant physiology: Adaptation-mitigation strategies under permanent stress. *Trends in Plant Science*, *20*(2), 72–75. https://doi.org/10.1016/j.tplants.2014.11.001

Canzonieri, C. (2007). M.E. Benedict and E.T. McMahon, Green Infrastructure: Linking Landscapes and Communities: Island Press, Washington, DC, USA. 2006, 299 pp. illus.; 26 cm. ISBN 1-55963-558-4 (paper); ISBN 1-59726-027-4 (cloth). *Landscape Ecology*, *22*(5), 797–798. https://doi.org/10.1007/s10980-006-9045-7

Carlos, J. S. (2015). Simulation assessment of living wall thermal performance in winter in the climate of Portugal. *Building Simulation*, *8*(1), 3–11. https://doi.org/10.1007/s12273-014-0187-2

Carrus, G., Scopelliti, M., Lafortezza, R., Colangelo, G., Ferrini, F., Salbitano, F., Agrimi, M., Portoghesi, L., Semenzato, P., & Sanesi, G. (2015). Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. *Landscape and Urban Planning*, *134*, 221–228. https://doi.org/10.1016/j.landurbplan.2014.10.022

Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., & Acuña, V. (2021a). Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Science of The Total Environment*, *779*, 146237. https://doi.org/10.1016/j.scitotenv.2021.146237

Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., & Acuña, V. (2021b). Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Science of The Total Environment*, *779*, 146237. https://doi.org/10.1016/j.scitotenv.2021.146237

Chauhan, A., & Saini, R. P. (2015). Renewable energy based off-grid rural electrification in Uttarakhand state of India: Technology options, modelling method, barriers and recommendations. *Renewable and Sustainable Energy Reviews*, *51*, 662–681. https://doi.org/10.1016/j.rser.2015.06.043

Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C. A. J., Kapos, V., Key, I., Roe, D., Smith, A., Woroniecki, S., & Seddon, N. (2020). Mapping the effectiveness of nature-based solutions for climate change adaptation. *Global Change Biology*, *26*(11), 6134–6155. https://doi.org/10.1111/gcb.15310

Chung, P.-W., Livesley, S. J., Rayner, J. P., & Farrell, C. (2021). Greywater irrigation can support climbing plant growth on building green façades. *Urban Forestry & Urban Greening*, *62*, 127119. https://doi.org/10.1016/j.ufug.2021.127119

Circular cities. (2022). *Call for STSM: Quantifying resource streams for decision support of implementing NBS for circularity and reuse – Circular City*. https://circular-city.eu/?p=900

City of Ljubjana. (2016). *European Green Capital 2016*. I feel Slovenia. https://www.ljubljana.si/en/ljubljana-for-you/european-green-capital-2016/

City of Novi Sad. (2011, September 21). *Geography | Novi Sad*. https://novisad.rs/eng/geography

City Population. (2022, June 13). *Slowenien—Größte Städte 2022*. Statista. https://de.statista.com/statistik/daten/studie/948564/umfrage/groesste-staedte-in-slowenien/

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds.). (2016). *Nature-based solutions to address global societal challenges*. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Connop, S., Vandergert, P., Eisenberg, B., Collier, M. J., Nash, C., Clough, J., & Newport, D. (2016). Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. *Environmental Science & Policy*, *62*, 99–111. https://doi.org/10.1016/j.envsci.2016.01.013

COST, T. E. C. in S. and T. (Ed.). (2021). *Join our European research networks*.

Cowan, C., Epple, C., Korn, H., Schliep, R., & Stadler, J. (Eds.). (n.d.). *Working with Nature to Tackle Climate Change*. 84.

Crona, B., & Hubacek, K. (2010). The Right Connections: How do Social Networks Lubricate the Machinery of Natural Resource Governance? *Ecology and Society*, *15*(4). https://doi.org/10.5751/ES-03731-150418

Cruz, J. A., Blanco, A. C., Garcia, J. J., Santos, J. A., & Moscoso, A. D. (2021). Evaluation of the cooling effect of green and blue spaces on urban microclimate through numerical simulation: A case study of Iloilo River Esplanade, Philippines. *Sustainable Cities and Society*, *74*, 103184. https://doi.org/10.1016/j.scs.2021.103184

Ćurić, M., Zafirovski, O., & Spiridonov, V. (2022). Human Biometeorology. In M. Ćurić, O. Zafirovski, & V. Spiridonov (Eds.), *Essentials of Medical Meteorology* (pp. 63–77). Springer International Publishing. https://doi.org/10.1007/978-3-030-80975-1_5

Davies, C., & Lafortezza, R. (2019). Transitional path to the adoption of nature-based solutions. *Land Use Policy*, *80*, 406–409. https://doi.org/10.1016/j.landusepol.2018.09.020

Davies, R. (2021, October 13). Carbon emissions 'will drop just 40% by 2050 with countries' current pledges'. *The Guardian*. https://www.theguardian.com/environment/2021/oct/13/carbon-emissions-will-drop-just-40-by-2050-with-countries-current-pledges

Davis, M., & Naumann, S. (2017). Making the Case for Sustainable Urban Drainage Systems as a Nature-Based Solution to Urban Flooding. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 123–137). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_8

de Abreu-Harbich, L. V., Labaki, L. C., & Matzarakis, A. (2015). Effect of tree planting design and tree species on human thermal comfort in the tropics. *Landscape and Urban Planning*, *138*, 99–109. https://doi.org/10.1016/j.landurbplan.2015.02.008

Dhakal, K. P., & Chevalier, L. R. (2016). Urban Stormwater Governance: The Need for a Paradigm Shift. *Environmental Management*, *57*(5), 1112–1124. https://doi.org/10.1007/s00267-016-0667-5

Dong, H., Fujita, T., Geng, Y., Dong, L., Ohnishi, S., Sun, L., Dou, Y., & Fujii, M. (2016). A review on eco-city evaluation methods and highlights for integration. *Ecological Indicators*, *60*, 1184–1191. https://doi.org/10.1016/j.ecolind.2015.08.044

Dudley, N., Stolton, S., Belokurov, lexander, Krueger, L., Lopoukhine, N., MacKinnon, K., Sandwith, T., & Sekhran, N. (2009, December 8). *Natural Solutions - Protected Areas: Helping people cope with climate change*. IUCN. https://www.iucn.org/content/natural-solutions-protected-areas-helping-people-cope-climate-change

Dunjić, J., Milošević, D., Kojić, M., Savić, S., Lužanin, Z., Šećerov, I., & Arsenović, D. (2021). Air Humidity Characteristics in "Local Climate Zones" of Novi Sad (Serbia) Based on Long-Term Data. *ISPRS International Journal of Geo-Information*, *10*(12), Article 12. https://doi.org/10.3390/ijgi10120810

Eggermont, H., Balian, E., Azevedo, M., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., Ham, C., Weisser, W., & Roux, X. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *Gaia: Okologische Perspektiven in Natur-, Geistes- Und Wirtschaftswissenschaften*, *24*, 243–248. https://doi.org/10.14512/gaia.24.4.9

Emilsson, T., & Ode Sang, Å. (2017). Impacts of Climate Change on Urban Areas and Nature-Based Solutions for Adaptation. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas* (pp. 15–27). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_2

Environment, U. N. (2021, July 27). *Climate Change Mitigation*. Global Environment Facility. http://www.unep.org/gef/index.php/focal-areas/climate-change-mitigation

Erell, E., Pearlmutter, D., Boneh, D., & Kutiel, P. B. (2014). Effect of high-albedo materials on pedestrian heat stress in urban street canyons. *Urban Climate*, *10*, 367–386. https://doi.org/10.1016/j.uclim.2013.10.005

EU. (2022, April 14). *Communication From The Commission To The European Economic And Social Committee And The Committee Of The Religions Closing the loop—An EU Action Plan for the Circular Economy*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614

European Environment Agency, Castellari, S., Zandersen, M., Davis, M., Veerkamp, C., Förster, J., Marttunen, M., Mysiak, J., Vandewalle, M., Medri, S., & Picatoste, J. R. (2021). *Nature-based solutions in Europe policy, knowledge and practice for climate change adaptation and disaster risk reduction*. Publications Office of the European Union. https://data.europa.eu/doi/10.2800/919315

Eurostat. (2022, September 12). *Budapest—Einwohnerzahl bis 2020*. Statista. https://de.statista.com/statistik/daten/studie/1332277/umfrage/entwicklung-der-gesamtbevoelkerung-in-budapest/

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research*, *159*, 509–518. https://doi.org/10.1016/j.envres.2017.08.032

Fastenrath, S., Bush, J., & Coenen, L. (2020). Scaling-up nature-based solutions. Lessons from the Living Melbourne strategy. *Geoforum*, *116*, 63–72. https://doi.org/10.1016/j.geoforum.2020.07.011

Feng, W., Ding, W., Zhen, M., Zou, W., & Wang, H. (2022). Cooling effect of urban small green spaces in Qujiang Campus, Xi'an Jiaotong University, China. *Environment, Development and Sustainability*, *24*(3), 4278–4298. https://doi.org/10.1007/s10668-021-01615-6

Fernandes, C. O., da Silva, I. M., Teixeira, C. P., & Costa, L. (2019). Between tree lovers and tree haters. Drivers of public perception regarding street trees and its implications on the urban green infrastructure planning. *Urban Forestry & Urban Greening*, *37*, 97–108. https://doi.org/10.1016/j.ufug.2018.03.014

Ferreira, C., Potočki, K., Kapovic Solomun, M., & Kalantari, Z. (2021). *Nature-Based Solutions for Flood Mitigation and Resilience in Urban Areas* (pp. 1–20). https://doi.org/10.1007/698_2021_758

Ferreira, C. S. S., Potočki, K., Kapović-Solomun, M., & Kalantari, Z. (2021). Nature-Based Solutions for Flood Mitigation and Resilience in Urban Areas. In C. S. S. Ferreira, Z. Kalantari, T. Hartmann, & P. Pereira (Eds.), *Nature-Based Solutions for Flood Mitigation* (Vol. 107, pp. 59–78). Springer International Publishing. https://doi.org/10.1007/698_2021_758

FOEN, F. O. for the E. (2021a, August 24). *Physical, chemical and biological soil pressures*. https://www.bafu.admin.ch/bafu/en/home/themen/thema-boden/boden--fachinformationen/physikalische--chemische-und-biologische-bodenbelastungen.html

FOEN, F. O. for the E. (2021b, August 25). *State of Swiss soil*. https://www.bafu.admin.ch/bafu/en/home/themen/thema-boden/boden--fachinformationen/zustand-der-schweizer-boeden.html

FOEN, F. O. for the E. (2022, March 31). *Circular economy*. https://www.bafu.admin.ch/bafu/en/home/themen/thema-wirtschaft-und-konsum/fachinformationen-wirtschaft-und-konsum/kreislaufwirtschaft.html

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, *93*, 101–111. https://doi.org/10.1016/j.envsci.2018.12.033

Frantzeskaki, N., Vandergert, P., Connop, S., Schipper, K., Zwierzchowska, I., Collier, M., & Lodder, M. (2020). Examining the policy needs for implementing nature-based solutions in cities: Findings from city-wide transdisciplinary experiences in Glasgow (UK), Genk (Belgium) and Poznań (Poland). *Land Use Policy*, *96*, 104688. https://doi.org/10.1016/j.landusepol.2020.104688

Fujii, M., Fujita, T., Dong, L., Lu, C., Geng, Y., Behera, S. K., Park, H.-S., & Chiu, A. S. F. (2016). Possibility of developing low-carbon industries through urban symbiosis in Asian cities. *Journal of Cleaner Production*, *114*, 376–386. https://doi.org/10.1016/j.jclepro.2015.04.027

Geletič, J., Lehnert, M., Savić, S., & Milošević, D. (2019). Inter-/intra-zonal seasonal variability of the surface urban heat island based on local climate zones in three central European cities. *Building and Environment*, *156*, 21–32. https://doi.org/10.1016/j.buildenv.2019.04.011

Geodatos. (2022a). *Budapest Geographic coordinates—Latitude & longitude*. https://www.geodatos.net/en/coordinates/hungary/budapest

Geodatos. (2022b). *Corduba Geographic coordinates—Latitude & longitude*. https://www.geodatos.net/en/coordinates/spain/corduba

Geodatos. (2022c). *Vienna, Austria Geographic coordinates—Latitude & longitude*. https://www.geodatos.net/en/coordinates/austria/vienna

Geodatos. (2022d). *Zürich Geographic coordinates—Latitude & longitude*. https://www.geodatos.net/en/coordinates/switzerland/zurich

Gholipour, A., Fragoso, R., Galvão, A., & Finger, D. C. (2023). Mapping the causality of interacting perceptions for nature-based solution and sludge treatment reed bed: A causal loop diagram in Iceland. *Nature-Based Solutions*, *3*, 100049. https://doi.org/10.1016/j.nbsj.2023.100049

Griffee, D. (2005). Research Tips: Interview Data Collection. *Journal of Developmental Education*.

Grün Stadt Zürich. (2020). *Landwirtschaft in Zürich*. https://www.stadt-zuerich.ch/ted/de/index/gsz/landwirtschaft-in-zuerich.html

Grün Stadt Zürich. (2022, June 16). *Ausstellung «Cool down Zurich – Wir kühlen die Stadt»—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/departement/medien/medienmitteilungen/2022/juni/220616a.html

Grün Stadt Zürich, Sutter, I., Tschander, B., Fachbereich Naturschutz, & TED, S. Z. T. E. (2020, July). *Zürcher Dachgrün für Ökologie, Klima und Wirtschaftlichkeit*. https://www.stadt-zuerich.ch/ted/de/index/gsz/beratung-und-wissen/wohn-und-arbeitsumfeld/dachbegruenungen0.html

Hajjar, R., Oldekop, J. A., Cronkleton, P., Newton, P., Russell, A. J. M., & Zhou, W. (2021). A global analysis of the social and environmental outcomes of community forests. *Nature Sustainability*, *4*(3), Article 3. https://doi.org/10.1038/s41893-020-00633-y

Hartmann, T., Slavíková, L., & McCarthy, S. (2019). Nature-Based Solutions in Flood Risk Management. In T. Hartmann, L. Slavíková, & S. McCarthy (Eds.), *Nature-Based Flood Risk Management on Private Land: Disciplinary Perspectives on a Multidisciplinary Challenge* (pp. 3–8). Springer International Publishing. https://doi.org/10.1007/978-3-030-23842-1_1

Harvard University, & NBER. (2022, December 20). *Geschichte: Einwohner der größten Städte in Europa 1050*. Statista.

https://de.statista.com/statistik/daten/studie/1067225/umfrage/einwohner-der-groessten-staedte-in-europa/

Hathway, E. A., & Sharples, S. (2012). The interaction of rivers and urban form in mitigating the Urban Heat Island effect: A UK case study. *Building and Environment*, *58*, 14–22. https://doi.org/10.1016/j.buildenv.2012.06.013

Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The Urban Heat Island: Implications for Health in a Changing Environment. *Current Environmental Health Reports*, *4*(3), 296–305. https://doi.org/10.1007/s40572-017-0150-3

Holzner, L., John Hill, R., & Holzner, L. (2022, October 6). *Vienna—Layout and architecture | Britannica*. https://www.britannica.com/place/Vienna

Hopkins, L. P., January-Bevers, D. J., Caton, E. K., & Campos, L. A. (2022). A simple tree planting framework to improve climate, air pollution, health, and urban heat in vulnerable locations using non-traditional partners. *PLANTS, PEOPLE, PLANET*, *4*(3), 243–257. https://doi.org/10.1002/ppp3.10245

Houston, J., Casazza, E., Briguglio, M., Spiteri, J., & European Comission. (2020). *Enablers and Barriers to a Circular Economy* (R2π Consortium Partners, Ed.).

Hoyle, H., Jorgensen, A., Warren, P., Dunnett, N., & Evans, K. (2017). “Not in their front yard” The opportunities and challenges of introducing perennial urban meadows: A local authority stakeholder perspective. *Urban Forestry & Urban Greening*, *25*, 139–149. https://doi.org/10.1016/j.ufug.2017.05.009

Huwald, H., Higgins, C. W., Boldi, M.-O., Bou-Zeid, E., Lehning, M., & Parlange, M. B. (2009). Albedo effect on radiative errors in air temperature measurements. *Water Resources Research*, *45*(8). https://doi.org/10.1029/2008WR007600

IUCN. (2020, July 14). *IUCN Global Standard for NbS*. IUCN. https://www.iucn.org/theme/nature-based-solutions/resources/iucn-global-standard-nbs

Jacobs, C., Klok, L., Bruse, M., Cortesão, J., Lenzholzer, S., & Kluck, J. (2020). Are urban water bodies really cooling? *Urban Climate*, *32*, 100607. https://doi.org/10.1016/j.uclim.2020.100607

Jänicke, B., Milošević, D., & Manavvi, S. (2021). Review of User-Friendly Models to Improve the Urban Micro-Climate. *Atmosphere*, *12*(10), Article 10. https://doi.org/10.3390/atmos12101291

Johns, C. M. (2019). Understanding barriers to green infrastructure policy and stormwater management in the City of Toronto: A shift from grey to green or policy layering and conversion? *Journal of Environmental Planning and Management*, *62*(8), 1377–1401. https://doi.org/10.1080/09640568.2018.1496072

Junta de Andalucía, & EU, E. U. S. N. (2011). *Córdoba—Offizielle Tourismus-Webseite von Andalusien*. https://www.andalucia.org/de/provincia-cordoba

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, *21*(2). https://www.jstor.org/stable/26270403

Kapos, V., Wicander, S., Salvaterra, T., Dawkins, K., & Hicks, C. (2019). *THE ROLE OF THE NATURAL ENVIRONMENT IN ADAPTATION*.

Keeley, M., Koburger, A., Dolowitz, D. P., Medearis, D., Nickel, D., & Shuster, W. (2013). Perspectives on the Use of Green Infrastructure for Stormwater Management in Cleveland and Milwaukee. *Environmental Management*, *51*(6), 1093–1108. https://doi.org/10.1007/s00267-013-0032-x

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havránek, M., Pataki, D., Phdungsilp, A., Ramaswami, A., & Mendez, G. V. (2009). Greenhouse Gas Emissions from Global Cities. *Environmental Science & Technology*, *43*(19), 7297–7302. https://doi.org/10.1021/es900213p

Kisser, J., Wirth, M., De Gusseme, B., Van Eekert, M., Zeeman, G., Schönborn, A., Vinnerås, B., Finger, D. C., Kolbl Repinc, S., Bulc, T. G., Bani, A., Pavlova, D., Staicu, L. C., Atasoy, M., Cetecioglu, Z., Kokko, M., Haznedaroglu, B. Z., Hansen, J., Istenič, D., … Beesley, L. (2020). A review of nature-based solutions for resource recovery in cities. *Blue-Green Systems*, *2*(1). https://doi.org/10.2166/bgs.2020.930

Klok, L., Rood, N., Kluck, J., & Kleerekoper, L. (2019). Assessment of thermally comfortable urban spaces in Amsterdam during hot summer days. *International Journal of Biometeorology*, *63*(2), 129–141. https://doi.org/10.1007/s00484-018-1644-x

Kong, F., Sun, C., Liu, F., Yin, H., Jiang, F., Pu, Y., Cavan, G., Skelhorn, C., Middel, A., & Dronova, I. (2016). Energy saving potential of fragmented green spaces due to their temperature regulating ecosystem services in the summer. *Applied Energy*, *183*, 1428–1440. https://doi.org/10.1016/j.apenergy.2016.09.070

Kong, L., Lau, K. K.-L., Yuan, C., Chen, Y., Xu, Y., Ren, C., & Ng, E. (2017). Regulation of outdoor thermal comfort by trees in Hong Kong. *Sustainable Cities and Society*, *31*, 12–25. https://doi.org/10.1016/j.scs.2017.01.018

Koop, S. H. A., & van Leeuwen, C. J. (2017). The challenges of water, waste and climate change in cities. *Environment, Development and Sustainability*, *19*(2), 385–418. https://doi.org/10.1007/s10668-016-9760-4

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger Climate Classification Updated. *Meteorologische Zeitschrift*, *15*, 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., & Fischer-Kowalski, M. (2009). Growth in global materials use, GDP and population during the 20th century. *Ecological Economics*, *68*(10), 2696–2705. https://doi.org/10.1016/j.ecolecon.2009.05.007

Lai, D., Liu, W., Gan, T., Liu, K., & Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of The Total Environment*, *661*. https://doi.org/10.1016/j.scitotenv.2019.01.062

Lane, J. L., de Haas, D. W., & Lant, P. A. (2015). The diverse environmental burden of city-scale urban water systems. *Water Research*, *81*, 398–415. https://doi.org/10.1016/j.watres.2015.03.005

Langergraber, G., Castellar, J. A. C., Pucher, B., Baganz, G. F. M., Milosevic, D., Andreucci, M.-B., Kearney, K., Pineda-Martos, R., & Atanasova, N. (2021). A Framework for Addressing Circularity Challenges in Cities with Nature-Based Solutions. *Water*, *13*(17), Article 17. https://doi.org/10.3390/w13172355

Langergraber, G., Pucher, B., Simperler, L., Kisser, J., Katsou, E., Buehler, D., Mateo, M. C. G., & Atanasova, N. (2020). Implementing nature-based solutions for creating a resourceful circular city. *Blue-Green Systems*, *2*(1), 173–185. https://doi.org/10.2166/bgs.2020.933

László, P. (2022, November 10). *Budapest | History, Language, Population, Climate, & Facts | Britannica*. Britannica. https://www.britannica.com/place/Budapest

Leal Filho, W., Wolf, F., Castro-Díaz, R., Li, C., Ojeh, V. N., Gutiérrez, N., Nagy, G. J., Savić, S., Natenzon, C. E., Quasem Al-Amin, A., Maruna, M., & Bönecke, J. (2021). Addressing the Urban Heat Islands Effect: A Cross-Country Assessment of the Role of Green Infrastructure. *Sustainability*, *13*(2), Article 2. https://doi.org/10.3390/su13020753

Lehnert, M., Tokar, V., Jurek, M., & Geletič, J. (2021). Summer thermal comfort in Czech cities: Measured effects of blue and green features in city centres. *International Journal of Biometeorology*, *65*(8), 1277–1289. https://doi.org/10.1007/s00484-020-02010-y

Li, H. (2016). Chapter 13—Impacts of Pavement Strategies on Human Thermal Comfort. In H. Li (Ed.), *Pavement Materials for Heat Island Mitigation* (pp. 281–306). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-12-803476-7.00013-1

Li, H., Ding, L., Ren, M., Li, C., & Wang, H. (2017). Sponge City Construction in China: A Survey of the Challenges and Opportunities. *Water*, *9*(9), Article 9. https://doi.org/10.3390/w9090594

Li, L., Collins, A. M., Cheshmehzangi, A., & Chan, F. K. S. (2020). Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China. *Urban Forestry & Urban Greening*, *54*, 126770. https://doi.org/10.1016/j.ufug.2020.126770

Liquete, C., Udias, A., Conte, G., Grizzetti, B., & Masi, F. (2016). Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. *Ecosystem Services*, *22*, 392–401. https://doi.org/10.1016/j.ecoser.2016.09.011

Lorenzoni, I., Nicholson-Cole, S., & Whitmarsh, L. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change*, *17*(3), 445–459. https://doi.org/10.1016/j.gloenvcha.2007.01.004

MacKinnon, K., van Ham, C., Reilly, K., & Hopkins, J. (2019). Nature-Based Solutions and Protected Areas to Improve Urban Biodiversity and Health. In M. R. Marselle, J. Stadler, H. Korn, K. N. Irvine, & A. Bonn (Eds.), *Biodiversity and Health in the Face of Climate Change* (pp. 363–380). Springer International Publishing. https://doi.org/10.1007/978-3-030-02318-8_16

Maes, J., & Jacobs, S. (2017). Nature-Based Solutions for Europe's Sustainable Development. *Conservation Letters*, *10*(1), 121–124. https://doi.org/10.1111/conl.12216

Matzarakis, A., & Mayer, H. (1996). Another kind of environmental stress: Thermal stress. *WHO Collaborating Centre for Air Quality Management and Air Pollution Control*, *18*, 7–10.

McVittie, A., Cole, L., Wreford, A., Sgobbi, A., & Yordi, B. (2018). Ecosystem-based solutions for disaster risk reduction: Lessons from European applications of ecosystem-based adaptation measures. *International Journal of Disaster Risk Reduction*, *32*, 42–54. https://doi.org/10.1016/j.ijdrr.2017.12.014

Mesimäki, M., & Lehvävirta, S. (2019). *ThinkNature Nature-Based Solutions Handbook* (Thinknature, Ed.). European Union. https://doi.org/10.26225/jerv-w202

Milošević, D., Middel, A., Savic, S., Dunjić, J., Lau, K., & Stojsavljević, R. (2022). Mask wearing behavior in hot urban spaces of Novi Sad during the COVID-19 pandemic. *Science of The Total Environment*, *815*, 152782. https://doi.org/10.1016/j.scitotenv.2021.152782

Milošević, D., Savić, S., Kresoja, M., Lužanin, Z., Šećerov, I., Arsenović, D., Dunjić, J., & Matzarakis, A. (2022). Analysis of air temperature dynamics in the "local climate zones" of Novi Sad (Serbia) based on long-term database from an urban meteorological network. *International Journal of Biometeorology*, *66*(2), 371–384. https://doi.org/10.1007/s00484-020-02058-w

Milošević, D., Savić, S. M., Marković, V., Arsenović, D., & Šećerov, I. (2016). Outdoor human thermal comfort in local climate zones of Novi Sad (Serbia) during heat wave period. *Hungarian Geographical Bulletin*, *65*(2), Article 2. https://doi.org/10.15201/hungeobull.65.2.4

Milošević, D., Savic, S., Secerov, I., & Dunjić, J. (2022, September 4). *Introducing Mobile Micrometeorological Carts (MMCs) for urban and non-urban micrometeorological measurements*.

Mohr, M. (2022, November 28). *Themenseite: Wien*. Statista. https://de.statista.com/themen/3459/grossstadt-wien/

Morakinyo, T. E., Kong, L., Lau, K. K.-L., Yuan, C., & Ng, E. (2017). A study on the impact of shadow-cast and tree species on in-canyon and neighborhood's thermal comfort. *Building and Environment*, *115*, 1–17. https://doi.org/10.1016/j.buildenv.2017.01.005

Müller, N., Kuttler, W., & Barlag, A.-B. (2014). Counteracting urban climate change: Adaptation measures and their effect on thermal comfort. *Theoretical and Applied Climatology*, *115*(1), 243–257. https://doi.org/10.1007/s00704-013-0890-4

Muñoz-Erickson, T. A., Campbell, L. K., Childers, D. L., Grove, J. M., Iwaniec, D. M., Pickett, S. T. A., Romolini, M., & Svendsen, E. S. (2016). Demystifying governance and its role for transitions in urban social–ecological systems. *Ecosphere*, *7*(11), e01564. https://doi.org/10.1002/ecs2.1564

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E., & Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of The Total Environment*, *579*, 1215–1227.

Northrop, E., Khan, M., Beguin Billecocq, I., Lecerf, M., Picourt, L., Thiele, T., Hemmerly, C., & Shekhar Yadav, S. (2022). *BLUE AMBITION LOOP: Achieving Ambitious 2030 Ocean-Climate Action*. https://ocean-climate.org/en/identifying-a-blue-ambition-loop-to-accelerate-ocean-based-climate-action/

O'Donnell, E. C., Lamond, J. E., & Thorne, C. R. (2017). Recognising barriers to implementation of Blue-Green Infrastructure: A Newcastle case study. *Urban Water Journal*, *14*(9), 964–971. https://doi.org/10.1080/1573062X.2017.1279190

O'Donnell, E. C., Lamond, J. E., & Thorne, C. R. (2018). Learning and Action Alliance framework to facilitate stakeholder collaboration and social learning in urban flood risk management. *Environmental Science & Policy*, *80*, 1–8. https://doi.org/10.1016/j.envsci.2017.10.013

OECD. (2015). *Environment at a Glance 2015: OECD Indicators*. OECD. https://doi.org/10.1787/9789264235199-en

OECD. (2020). *Nature-based solutions for adapting to water-related climate risks*. OECD. https://doi.org/10.1787/2257873d-en

Oliveira, A., Lopes, A., Correia, E., Niza, S., & Soares, A. (2021). An urban climate-based empirical model to predict present and future patterns of the Urban Thermal Signal. *Science of The Total Environment*, *790*, 147710. https://doi.org/10.1016/j.scitotenv.2021.147710

Olsson, P., Galaz, V., & Boonstra, W. (2014). Sustainability transformations: A resilience perspective. *Ecology and Society*, *19*(4). https://doi.org/10.5751/ES-06799-190401

Österreich Werbung. (2020). *Vienna – the greenest city in the world*. Holidays in Austria. https://www.austria.info/en/in-harmony-with-austria/imperial-vienna/vienna-the-world-s-greenest-city

Pacific Institute, & United Nations Global CEO Water Mandate (Eds.). (2022). *Stakeholder Engagement Guide For Nature-Based Solutions*.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., & Taillieu, T. (2007). Social Learning and Water Resources Management. *Ecology and Society*, *12*(2). https://www.jstor.org/stable/26267868

Pearlmutter, D., Pucher, B., Calheiros, C. S. C., Hoffmann, K. A., Aicher, A., Pinho, P., Stracqualursi, A., Korolova, A., Pobric, A., Galvão, A., Tokuç, A., Bas, B., Theochari, D., Milosevic, D., Giancola, E., Bertino, G., Castellar, J. A. C., Flaszynska, J., Onur, M., … Nehls, T. (2021). Closing Water Cycles in the Built Environment through Nature-Based Solutions: The

Contribution of Vertical Greening Systems and Green Roofs. *Water*, *13*(16), Article 16. https://doi.org/10.3390/w13162165

Pelling, M. (2004). *Disaster risk reduction: A development concern*. https://www.semanticscholar.org/paper/Disaster-risk-reduction-%3A-a-development-concern-Pelling/68936c720813d7638ef772bb61751ba2cf054ec4

Peng, L. L. H., Jiang, Z., Yang, X., Wang, Q., He, Y., & Chen, S. S. (2020). Energy savings of block-scale facade greening for different urban forms. *Applied Energy*, *279*, 115844. https://doi.org/10.1016/j.apenergy.2020.115844

Popov, T., Gnjato, S., & Trbić, G. (2019). Changes in extreme temperature indices over the Peripannonian region of Bosnia and Herzegovina. *Geografie*, *124*(1), 19–40. https://doi.org/10.37040/geografie2019124010019

Popov, T., Gnjato, S., Trbić, G., & Ivanišević, M. (2017). Trends in extreme daily precipitation indices in Bosnia and Herzegovina. *Zbornik Radova - Geografski Fakultet Univerziteta u Beogradu*, *65–1a*, 5–24. https://doi.org/10.5937/zrgfub1765005P

Price, R. (2021). *Nature-based Solutions (NbS) – What are They and What are the Barriers and Enablers to Their Use?* https://doi.org/10.19088/K4D.2021.098

Rahman, M. A., Armson, D., & Ennos, A. R. (2015). A comparison of the growth and cooling effectiveness of five commonly planted urban tree species. *Urban Ecosystems*, *18*(2), 371–389. https://doi.org/10.1007/s11252-014-0407-7

Rall, E. L., & Haase, D. (2011). Creative intervention in a dynamic city: A sustainability assessment of an interim use strategy for brownfields in Leipzig, Germany. *Landscape and Urban Planning*, *100*(3), 189–201. https://doi.org/10.1016/j.landurbplan.2010.12.004

Rayfield, B., Fortin, M.-J., & Fall, A. (2011). Connectivity for conservation: A framework to classify network measures. *Ecology*, *92*(4), 847–858. https://doi.org/10.1890/09-2190.1

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, *77*, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Republic Hydrometeorological Service, & Republic of Serbia (Eds.). (2022). *Seasonal Climate Outlook Of Serbia*.

Sarabi, S., Han, Q., Romme, A. G. L., de Vries, B., Valkenburg, R., & den Ouden, E. (2020). Uptake and implementation of Nature-Based Solutions: An analysis of barriers using

Interpretive Structural Modeling. *Journal of Environmental Management*, *270*, 110749. https://doi.org/10.1016/j.jenvman.2020.110749

Sarabi, S., Han, Q., Romme, G., Vries, de, & Wendling, L. (2019). Key Enablers of and Barriers to the Uptake and Implementation of Nature-Based Solutions in Urban Settings: A Review. *Resources*, *8*. https://doi.org/10.3390/resources8030121

Savaget, P., Geissdoerfer, M., Kharrazi, A., & Evans, S. (2019). The theoretical foundations of sociotechnical systems change for sustainability: A systematic literature review. *Journal of Cleaner Production*, *206*, 878–892. https://doi.org/10.1016/j.jclepro.2018.09.208

Savić, S., Marković, V., Šećerov, I., Pavić, D., Arsenović, D., Milošević, D., Dolinaj, D., Nagy, I., & Pantelić, M. (2018). Heat wave risk assessment and mapping in urban areas: Case study for a midsized Central European city, Novi Sad (Serbia). *Natural Hazards*, *91*(3), 891–911. https://doi.org/10.1007/s11069-017-3160-4

Schönborn, A., & Junge, R. (2021). Redefining ecological engineering in the context of circular economy and sustainable development. *Circular Economy and Sustainability*, *1*(1), 375–394. https://doi.org/10.1007/s43615-021-00023-2

Bundesgesetz über den Schutz der Gewässer (Gewässerschutzgesetz, GSchG), Pub. L. No. 814.201 (1997).

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190120. https://doi.org/10.1098/rstb.2019.0120

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., House, J., Srivastava, S., & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology*, *27*(8), 1518–1546. https://doi.org/10.1111/gcb.15513

Sonneveld, B. G. J. S., Merbis, M. D., Alfarra, A., Unver, I. H. O., Arnal, M. F., & Food and Agriculture Organization of the United Nations. (2018). *Nature-based solutions for agricultural water management and food security*.

Sorrell, S. (2015). Reducing energy demand: A review of issues, challenges and approaches. *Renewable and Sustainable Energy Reviews*, *47*, 74–82. https://doi.org/10.1016/j.rser.2015.03.002

Bauordnung der Stadt Zürich, 686 12 (2018).

Stadt Zürich. (2022a). *Hochwasser—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/taz/fachunterlagen/naturgefahren/hochwasser.html

Stadt Zürich. (2022b). *Reinigungsstufen*. https://www.stadt-zuerich.ch/ted/de/index/entsorgung_recycling/wissen/wasser/klaerwerk/reinigungsstufen.html

Stadt Zürich. (2022c). *Startseite Portal der Stadt Zürich—Stadt Zürich*. https://www.stadt-zuerich.ch/portal/de/index.html

Stadt Zürich. (2022d). *Was ist Kreislaufwirtschaft—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/entsorgung_recycling/wissen/kreislaufwirtschaft/was-ist-kreislaufwirtschaft.html

Stadt Zürich. (2022e, June 15). *Zürich in Zahlen—Stadt Zürich*. https://www.stadt-zuerich.ch/portal/de/index/portraet_der_stadt_zuerich/zuerich_in_zahlen.html

Stadt Zürich, & Grün Stadt Zürich (Eds.). (2020). *Fachplanung Hitzeminderung—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/gsz/planung-und-bau/fachplanung-hitzeminderung.html

Stadt Zürich (Hrsg.) (Ed.). (2020). *Fachplanung Hitzeminderung*. https://www.stadt-zuerich.ch/ted/de/index/gsz/planung-und-bau/fachplanung-hitzeminderung.html

Stadt Zürich Präsidialdepartement. (2022, March 7). *Bevölkerungsbestand und -entwicklung—Stadt Zürich*. https://www.stadt-zuerich.ch/prd/de/index/statistik/themen/bevoelkerung/bevoelkerungsentwicklung/aktueller-bevoelkerungsbestand.html

statista. (2021). *Zürich*. Statista. https://de.statista.com/statistik/studie/id/88782/dokument/zuerich/

Statistics Iceland. (2022, December 22). *Island—Größte Städte 2022*. Statista. https://de.statista.com/statistik/daten/studie/1103239/umfrage/groesste-staedte-in-island/

Statistik, B. für. (2018). *Versiegelungsgrad*. https://www.bfs.admin.ch/bfs/de/home/statistiken/raum-umwelt/bodennutzung-bedeckung/siedlungsflaechen/versiegelungsgrad.html

Statistik, B. für. (2021, November 25). *Arealstatistik Land Cover—Versiegelte Flächen der Kantone und Grossregionen—1979-1985, 1992-1997, 2004-2009, 2013-2018 | Tabelle*. Bundesamt für Statistik. https://www.bfs.admin.ch/asset/de/19805726

Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, *93*(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Stirling, A., Lobstein, T., Millstone, E., & PorGrow Research Team. (2007). Methodology for obtaining stakeholder assessments of obesity policy options in the PorGrow project. *Obesity Reviews: An Official Journal of the International Association for the Study of Obesity*, *8 Suppl 2*, 17–27. https://doi.org/10.1111/j.1467-789X.2007.00355.x

Szulczewska, B., Giedych, R., Borowski, J., Kuchcik, M., Sikorski, P., Mazurkiewicz, A., & Stańczyk, T. (2014). How much green is needed for a vital neighbourhood? In search for empirical evidence. *Land Use Policy*, *38*, 330–345. https://doi.org/10.1016/j.landusepol.2013.11.006

Tagblatt (Ed.). (2019). Schweizer Unternehmen klagen über zu viel Bürokratie. *St. Galler Tagblatt*. https://www.tagblatt.ch/newsticker/schweiz/schweizer-unternehmen-klagen-uber-zu-viel-burokratie-ld.1107533

TED, S. Z. T. E. (2020, December 3). *Hitzeminderung: Stadt Zürich testet Elemente der Schwammstadt - Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/departement/medien/medienmitteilungen/2020/dezember/201203a.html

TED, S. Z. T. E. (2021, December 2). *Fördergelder für grüne Fassaden, Dächer und Aussenräume—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/departement/medien/medienmitteilungen/2021/dezember/211202a.html

TED, S. Z. T. E. (2022a). *Beläge—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/taz/erhalten/standards_stadtraeume_zuerich/elementkatalog_auswahl/belaege_randabschluesse/belaege.html

TED, S. Z. T. E. (2022b). *Dachbegrünungen—Stadt Zürich*. https://www.stadt-zuerich.ch/ted/de/index/gsz/beratung-und-wissen/wohn-und-arbeitsumfeld/dachbegruenungen0.html

Thorsson, S., Lindberg, F., Eliasson, I., & Holmer, B. (2007). Different methods for estimating the mean radiant temperature in an outdoor urban setting. *International Journal of Climatology*, *27*(14), 1983–1993. https://doi.org/10.1002/joc.1537

Toxopeus, H., & Polzin, F. (2021). Reviewing financing barriers and strategies for urban nature-based solutions. *Journal of Environmental Management*, *289*, 112371. https://doi.org/10.1016/j.jenvman.2021.112371

UFAM, B. für U. B. | O. fédéral de l'environnement O. | U. federale dell'ambiente. (2018). *Hitze in Städten*. https://www.bafu.admin.ch/bafu/de/home/themen/thema-klima/klima--publikationen-und-studien/publikationen-klima/hitze-in-staedten.html

UFAM, B. für U. B. | O. fédéral de l'environnement O. | U. federale dell'ambiente. (2021, July 26). *Hochwasser Juli 2021: Intensive Niederschläge führten verbreitet zu Überschwemmungen*. https://www.bafu.admin.ch/bafu/de/home/themen/thema-wasser/wasser--dossiers/hochwasser-juli-2021-intensive-niederschlaege-fuehrten-verbreitet-zu-ueberschwemmungen.html

UFAM, B. für U. B. | O. fédéral de l'environnement O. | U. federale dell'ambiente. (2022a). *Regenwasser im Siedlungsraum*. https://www.bafu.admin.ch/bafu/de/home/themen/thema-klima/klima--publikationen-und-studien/publikationen-klima/regenwasser-im-siedlungsraum.html

UFAM, B. für U. B. | O. fédéral de l'environnement O. | U. federale dell'ambiente. (2022b, January 26). *Langfristige Klimastrategie 2050*. https://www.bafu.admin.ch/bafu/de/home/themen/thema-klima/klimawandel-stoppen-und-folgen-meistern/massnahmen-der-schweiz-zur-verminderung-ihrer-treibhausgasemissionen/ziele-der-schweiz-zur-verminderung-ihrer-treibhausgasemissionen/indikatives-ziel-2050/langfristige-klimastrategie-2050.html

UFAM, B. für U. B. | O. fédéral de l'environnement O. | U. federale dell'ambiente. (2022c, March 31). *Kreislaufwirtschaft*. https://www.bafu.admin.ch/bafu/de/home/themen/thema-wirtschaft-und-konsum/fachinformationen-wirtschaft-und-konsum/kreislaufwirtschaft.html

UN environment programme, & Schweizerische Eidgenossenschaft. (2021, February 24). *Nature-based Solutions*. Geneva Environment Network. https://www.genevaenvironmentnetwork.org/resources/updates/nature-based-solutions/

UN environment programme, Schweizerische Eidgenossenschaft, & Pollini, R. (2021, October 25). *Nature-based Solutions and Cities | Geneva Nature-based Solutions Dialogues*. https://www.genevaenvironmentnetwork.org/events/nature-based-solutions-and-cities/

UNEP. (2011). *Towards a Green economy: Pathways to Sustainable Development and Poverty Eradication—A Synthesis for Policy Makers*.

UNEP. (2019, September 22). *Scaling-up Nature-Based Solutions for Mitigation, Resilience and Adaptation*. UNEP. http://www.unep.org/news-and-stories/speech/scaling-nature-based-solutions-mitigation-resilience-and-adaptation

United Nations Global Compact, WE MEAN BUSINESS, & World Resource Institute. (2018, November). *The Ambition Loop*. The Ambition Loop. https://ambitionloop.org

Unity College. (2017, March 23). *The Importance of Quantitative Methods in Environmental Science and Sustainability Measurement*. Unity College. https://unity.edu/sustainability/importance-quantitative-methods-environmental-science-sustainability-measurement/

Urban GreenUp. (2019). *D1.5—Barriers and Boundaries Identification*.

van der Jagt, A. P. N., Kiss, B., Hirose, S., & Takahashi, W. (2021). Nature-Based Solutions or Debacles? The Politics of Reflexive Governance for Sustainable and Just Cities. *Frontiers in Sustainable Cities*, *2*. https://www.frontiersin.org/articles/10.3389/frsc.2020.583833

van Ham, C., & Klimmek, H. (2017). Partnerships for Nature-Based Solutions in Urban Areas – Showcasing Successful Examples. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice* (pp. 275–289). Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_16

Van Renterghem, T., Botteldooren, D., & Verheyen, K. (2012). Road traffic noise shielding by vegetation belts of limited depth. *Journal of Sound and Vibration*, *331*(10), 2404–2425. https://doi.org/10.1016/j.jsv.2012.01.006

Varvasovszky, Z., & Brugha, R. (2000). A stakeholder analysis. *Health Policy and Planning*, *15*(3), 338–345. https://doi.org/10.1093/heapol/15.3.338

Verein für Ingenieurbiologie, c/o HSR Hochschule für Technik Rapperswil, & ILF-Institut für Landschaft und Freiraum. (2017, December). *Ingenieurbiologie. Genie Biologique. Ingegneria Naturalistica. 4*. https://issuu.com/ingenieurbiologie/docs/ingenieurbiologie_2017_4

Wang, Y., Bakker, F., de Groot, R., Wortche, H., & Leemans, R. (2015). Effects of urban trees on local outdoor microclimate: Synthesizing field measurements by numerical modelling. *Urban Ecosystems*, *18*(4), 1305–1331. https://doi.org/10.1007/s11252-015-0447-7

Webb, B. (2016). The use of urban climatology in local climate change strategies: A comparative perspective. *International Planning Studies*, *22*(2), 68–84. https://doi.org/10.1080/13563475.2016.1169916

Writer, S. (2022, April 11). *Reykjavík (Capital City of Iceland): Things to do in Reykjavik*. Iceland.Org. https://www.iceland.org/reykjavik/

Zhang, B., Xie, G., Gao, J., & Yang, Y. (2014). The cooling effect of urban green spaces as a contribution to energy-saving and emission-reduction: A case study in Beijing, China. *Building and Environment*, *76*, 37–43. https://doi.org/10.1016/j.buildenv.2014.03.003

Zingraff-Hamed, A., Hüesker, F., Lupp, G., Begg, C., Huang, J., Oen, A., Vojinovic, Z., Kuhlicke, C., & Pauleit, S. (2020). Stakeholder Mapping to Co-Create Nature-Based Solutions: Who Is on Board? *Sustainability*, *12*(20), Article 20. https://doi.org/10.3390/su12208625

Zwierzchowska, I., Fagiewicz, K., Poniży, L., Lupa, P., & Mizgajski, A. (2019). Introducing nature-based solutions into urban policy – facts and gaps. Case study of Poznań. *Land Use Policy*, *85*, 161–175. https://doi.org/10.1016/j.landusepol.2019.03.025

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Appendix I Interview guide for the Stakeholder-analysis from the COST Action on Circular Cities

Guide (interview questions):

(*Probably we will not have answers for all the questions, if it is clear that someone has no information about something, then we can jump the question.)

Introduction of the research:

As a part of the COST Action on Circular Cities we conduct a comparative research exploring the factors influencing urban planning and city council policies, in order to better understand the use of NBS in urban planning. **The research will cover the sectors water management, resource recovery, urban agriculture building and climate change mitigation.**

The interviews will be recorded, transcribed and anonymised, the participation in our research is voluntary.

1. Please introduce yourself, and the organization you represent!
    a. *Additional questions, to foster the interview (if necessary).
    b. What are the tasks and responsibilities of the organization? (*If not mentioned, ask directly about the most important topics: urban planning, public infrastructure maintenance and investments, water management, resource recovery, urban agriculture, urban green areas)
2. Have you heard of the concept of Nature-based solutions?
    a. If yes, then interviewee should explain in 1-3 sentences what is NBS for him/her and his/her organization?
    b. How NBS appears/is used in your organization (*short definition, if asked)?
    c. If interviewee did not hear about NBS concept, then interviewer should shortly explain the NBS concept to the interviewee and ask him/her how they call NBS (i.e., which synonym they use - for example, ecosystem services)

Make a list of the 5 topics and choose where to start!

3. We plan to discuss 5 topics:
    a. water management
    b. resource recovery
    c. urban gardening
    d. built environment
    e. climate change mitigation

    With which one would you start?

4. Please tell me about the role of your organization in **topic a, b, c, d or e**! How does it appear among your tasks, how can you influence decisions? (*IT IS POSSIBLE, THAT THEY ONLY HAVE MINOR ON NO INFLUENCE ON IT, THEN WE CAN ASK ABOUT HER/HIS OPINION)

   Ask for examples!

   a. What are the main problems, possibilities, challenges in water management?
   b. Talk about the **topic a, b, c, d or e** of the city!
   c. Who are the main actors in planning, managing **topic a, b, c, d or e**?
   d. What are the most relevant laws & documents that guide your decision about the use of NBS?
   e. Which stakeholders do you think are responsible for the implementation?
   f. How sustainable are the present practice? How could it be improved?
   g. Which NBSs does your organization implement for **topic a, b, c, d or e**?
      i. Why these NBSs (name 2-4 main reasons)?
      ii. Is there a NBS which you would like to use in the future?
      iii. Which are the main obstacles preventing the implementation of NBS (law, standards, lack of knowledge among designers, cost/benefit, maintenance)

5. What do you think the city will look like in 10 years? How do you see the role of NBS in the next 10 years?
6. Please recommend us actors/stakeholders, whom we should contact and ask for interviews.

Appendix II Micro Meteorological Carts Data from 17.08.2022

Appendix II.a) Micro Meteorological Carts Data of air temperature (Ta), relative humidity (RH), wind velocity (v), globe temperature (Tg), Median Radiant Temperature (Tmrt), Physiologically Equivalent Temperature (PET) and solar radion (Sr) from MCC1.

National Theatre Square - near fountain							
Time	Ta (C°)	RH (%)	v (m/s)	Tg (C°)	PET (C°)	Tmrt (C°)	Sr (W/m2)
08:00:00	25.6	57	0.9	27.75	26.6	32.2292441	35
08:02:00	25.6	57	0.9	27.75	26.6	32.2292441	35
12:06:00	31.1	43	0.4	37.75	38	45.361203	747
15:00:00	33.3	32	0.9	48.25	51.6	71.6930356	165
15:02:00	33.3	33	0.7	48	50.5	68.1713503	688
19:34:00	32.8	35	0.5	35.75	36	39.7539456	3
08:04:00	25.6	57	0.9	28.5	28.25	33.716841	27.3
08:06:00	25.6	57	0.9	28.25	28.25	32.969122	27.4
12:02:00	31.1	43	1.4	41	43.8	62.7858713	747
15:04:00	33.3	34	0.4	52.5	53.6	70.7447769	688
19:30:00	32.8	35	0.5	36.25	36.5	40.8956215	7
08:08:00	25.6	57	0.5	28.5	28.5	32.7202611	27.9
12:00:00	31.1	44	0.3	39.75	40.4	47.902837	743
19:28:00	32.8	34	0.5	36.25	35.9	40.8956215	7
08:10:00	25.6	57	0.7	27.75	27.75	30.0918043	27.3
11:58:00	30.6	43	1.5	38.75	40.9	58.0618534	743
15:08:00	33.3	32	0	55.25	47.6	55.25	673
19:26:00	32.8	35	0.3	36.5	36.5	40.1754385	8
08:12:00	25.6	57	0.4	28.5	28	32.2009424	37
11:56:00	30.6	43	0.9	36	36.7	46.1013253	743
15:10:00	33.9	32	0	57.75	49.5	57.75	676
19:24:00	32.8	33	0.6	36.25	36.6	41.4195463	10
08:14:00	25.6	57	1	28.5	27.5	34.8301561	38
11:54:00	30.6	43	2.1	35	35.8	48.5850416	741
15:12:00	33.9	32	0.4	58.5	60	80.312617	683
19:22:00	32.8	33	0	36.5	35.4	36.5	10
08:16:00	25.6	57	0.6	28.25	27.5	32.5609511	38
11:52:00	30.6	44	1.8	33.5	33.6	41.9882022	738
15:14:00	33.9	32	2	55.5	64.6	101.791095	687
19:20:00	32.8	34	0.1	37	36.5	39.1635397	12

08:18:00	25.6	57	1.1	28.5	27.4	35.1907408	38
11:50:00	30.6	44	1.5	33.75	34	42.0040493	736
15:16:00	33.9	32	0.4	54.75	56	74.0740531	683
19:18:00	32.8	33	0.3	36.25	36.2	39.6892905	14
08:20:00	25.6	56	1.6	28.5	27.1	36.8105079	38
08:22:00	25.6	57	0.5	28.75	28.1	33.3149715	38
11:48:00	30.6	44	2	34	34.3	44.4500667	736
15:20:00	33.9	32	1	55.5	61	87.9804338	660
19:14:00	32.8	33	0.8	37.25	37.9	45.0015375	14
08:24:00	25.6	56	0.8	28.25	27.3	33.3530391	40
11:44:00	30.6	44	1.4	33.75	34	41.6817696	731
15:22:00	33.9	31	2.6	54.5	64.6	105.530415	650
19:12:00	33.3	34	0.6	36.75	37.2	41.8953724	15
08:26:00	25.6	56	0.5	28	27.3	31.5221328	40
11:42:00	30.6	45	1.6	33.5	33.6	41.4305512	725
15:24:00	33.9	31	1.5	52	58.4	87.3321882	641
19:10:00	33.3	32	0.4	37.25	37.4	41.8587196	17
08:30:00	25.6	56	0.6	28.75	28.1	33.8297126	40
08:32:00	25.6	56	0.9	28.75	27.9	35.1854373	40
11:36:00	30	45	0.8	34	34.2	41.2074099	622
15:30:00	34.4	30	2.1	53	61.3	95.6248365	630
19:06:00	33.3	33	0.6	37.75			19
08:34:00	25.6	56	1.2	28.75	27.7	36.3537936	42
11:34:00	30	46	1	33.75	34	41.474185	414
15:32:00	34.4	30	2	52	59.7	91.9815719	618
19:02:00	33.3	32	0.5	37.75			21
08:36:00	26.1	56	1.4	28.75	27.6	35.7864375	42
11:32:00	30	46	0.8	33.25	33.3	39.1853346	195
15:36:00	34.4	31	1.2	54	59.9	87.2039644	606
18:58:00	33.3	32	0.4	37.5			24
08:38:00	26.1	56	1	28.75	27.8	34.5358179	42
11:30:00	30	46	1.3	33.25	33.3	41.1179955	72
15:38:00	34.4	31	1.6	54.25	61.7	93.1245947	585
18:56:00	33.3	32	0.1	38.5			24
08:40:00	26.1	56	0.6	28.5	27.8	32.402527	42
08:42:00	26.1	56	0.5	28.75	28.2	32.603932	42

11:24:00	30	46	1.5	32.25	32	38.2968076	70
15:42:00	34.4	30	1.1	52	57	81.3105191	586
18:52:00	33.3	32	0.4	38.25	38.5	43.9407753	28
08:44:00	26.1	57	0.7	29	28.3	34.1161918	42
08:46:00	26.1	56	1.3	28.75	27.6	35.4902894	42
11:22:00	30	46	1.6	33	33	41.2316626	70
15:44:00	34.4	30	0.8	53	56.8	78.7734362	597
18:50:00	33.3	32	0.7	38.25	39	46.1283463	29
08:48:00	26.1	55	1.7	29	27.8	37.5654405	42
11:20:00	30	46	1.2	32.75	32.7	39.1713331	70
15:46:00	34.4	30	0.4	54.75	56	73.6471294	593
18:48:00	33.3	32	0.1	39	38.2	41.8705907	31
08:50:00	26.1	54	1.7	29	27.7	37.5654405	44
11:18:00	29.4	47	1.3	33	33.1	41.7009955	70
15:48:00	34.4	30	1	55.5	60.9	87.3222642	592
18:46:00	33.3	32	0.3	38.75	38.8	44.0081043	33
08:52:00	26.1	54	1.3	28.75	27.6	35.4902894	44
11:16:00	29.4	47	0.5	32.25	32.1	36.2518928	70
15:50:00	34.4	30	1.3	55.25	61.9	91.4243918	586
18:44:00	33.3	32	0.5	38.75	39.2	45.8317795	33
08:54:00	26.1	54	0.9	28.75	27.8	34.1906733	44
11:14:00	29.4	47	1.6	32.75	32.7	41.9220916	132
15:52:00	34.4	29	0.8	55	59.2	82.7922414	574
18:40:00	33.3	31	0.7	39.25	40.2	48.5661853	37
08:56:00	26.1	54	1.2	29.25	28.3	36.8179489	44
11:12:00	29.4	47	2.1	32.5	32.3	42.4767384	315
15:54:00	35	30	0.9	54.25	58.9	82.2769476	569
18:38:00	33.3	32	0.7	39.75	40.8	49.7678641	38
09:00:00	26.1	54	1.1	29	28	35.6589908	44
11:08:00	29.4	48	0.9	32.75	32.7	39.3272338	165
15:58:00	34.4	30	1.6	53	60	90.1149251	549
18:34:00	33.3	31	1.2	39.25	40.8	51.918924	42
09:04:00	26.1	54	1.8	29.25	28.1	38.8079988	45
11:04:00	29.4	47	0.9	32.25	32.1	37.8984107	259
16:00:00	34.4	31	1.4	53.5	60	88.8110281	540
18:32:00	33.3	31	2.4	39.75	42.5	59.7587758	45
09:06:00	26.7	54	0.7	29.5	28.9	34.4202962	45

11:00:00	28.9	47	1.6	32.25	32	41.4646247	66
11:02:00	29.4	47	0.7	32.25	32.1	37.1262045	111
16:02:00	34.4	32	0.6	54	56.8	76.9443152	540
18:30:00	33.3	31	1.6	40.25	42.6	57.3122247	45

Appendix II.b) Micro Meteorological Carts Data of air temperature (Ta), relative humidity (RH), wind velocity (v), globe temperature (Tg), Median Radiant Temperature (Tmrt), Physiologically Equivalent Temperature (PET) and solar radion (Sr) of MCC2

National Theatre Square - near fountain								
Time	Ta (C°)	RH (%)	v (m/s)	Tg (C°)	Tmrt (C°)	PET (C°)	Sr (W/m2)	Sun/Shade
08:00:00	25.6	56	2.1	27.75	35.0919919	25.8	334	Sun
08:02:00	25.6	56	1.3	28.25	35.0224357	27	340	Sun
12:06:00	31.1	43	0.9	40.75	57.4734877	42.6	784	Sun
15:00:00	33.3	33	0.9	40	51.9601655	41.4	311	Cloudy weather
15:02:00	33.3	32	0.9	38.75	48.6895195	39.9	710	Sun
19:34:00	32.8	34	0.7	34.25	36.7119205	34.3	5	Shade
Under a tree near National Theatre Square								
08:04:00	25.6	56	2.2	26	27.4716877	23	24	Shade
08:06:00	25.6	56	1.5	25.5	25.2035261	23	33	Shade
12:02:00	31.1	42	2.5	37.5	58.2078037	39.6	82	Shade
15:04:00	33.9	32	0.8	42.75	56.945837	44.6	701	Mixed shade
19:30:00	32.8	34	1.2	34.5	38.4500663	34.6	7	Shade
Passageway under the City Hall								
08:08:00	25.6	56	0.7	26.75	28.8558538	25.6	31	Shade
12:00:00	31.1	42	1.3	39.25	57.0202044	41.3	56	Shade
19:28:00	32.8	34	0.8	34.25	36.91465	34.3	0	Shade
Main Square								
08:10:00	25.6	56	1.2	29.75	39.5626537	29	357	Sun
11:58:00	31.1	42	2.4	39.5	64.9538996	42.6	764	Sun
15:08:00	33.9	32	0.7	40.5	50.6712197	41.7	696	Sun
19:26:00	32.8	33	1.5	34.75	39.8878083	35	7	Shade

Urban canyon 1 near Church								
08:12:00	26.1	56	0.7	31	39.3432643	30.7	10	Shade
11:56:00	31.1	42	2.2	38	58.5923172	40.2	26	Shade
15:10:00	33.9	32	0.9	45.5	64.5338468	48.2	694	Sun
19:24:00	32.8	33	0.4	34.75	37.1063074	34.8	8	Shade
Small square with fountain near Church								
08:14:00	26.1	55	1.8	28.75	36.8871929	27.4	354	Sun
11:54:00	31.1	43	1.5	40.5	62.1712876	43.2	42	Shade/Sun
15:12:00	33.9	32	1.2	46.75	70.9388945	50.6	703	Sun
19:22:00	32.8	33	1.1	35	39.8083139	35.2	10	Shade
Urban canyon 2 near Church								
08:16:00	26.1	55	1.5	28.25	34.2599148	26.8	47	Shade
11:52:00	31.1	42	1.2	38.75	54.8498524	40.5	58	Shade
15:14:00	33.9	32	1	44.5	63.225306	47.2	63	Shade
19:20:00	32.8	33	1.1	34.75	39.0331403	34.9	10	Shade
Under a glass overhang - Yettel company								
08:18:00	26.1	55	1.7	28	33.7469239	26.3	38	Shade
11:50:00	31.1	43	1	37.75	50.6111601	39	24	Shade
15:16:00	33.9	32	0.9	41.25	54.1593561	43	734	Shade
19:18:00	32.8	33	0.9	34.75	38.5560919	34.9	3	Shade
Hallway under Hotel Vojvodina								
08:20:00	26.1	55	1.1	29	35.6589908	28.1	45	Shade
08:22:00	26.1	56	1.2	29.25	36.8179489	28.4	59	Shade
11:48:00	31.1	43	0.4	39.25	48.3794241	39.6	24	Shade
15:20:00	33.9	32	0.7	39.25	47.6629658	40.2	5	Shade
19:14:00	32.8	33	0.6	34.5	37.1229585	34.6	10	Shade
Garden of Hotel Vojvodina - open								
08:24:00	26.1	56	1	29	35.3000477	28.1	44	Cloudy weather
11:44:00	31.1	42	1.2	35.75	46.0994539	36.5	761	Sun
15:22:00	33.9	32	1	38.5	47.4984181	39.6	44	Shade
19:12:00	32.8	33	1	34.75	38.799669	34.9	8	Shade

Garden of Hotel Vojvodina - under a tree								
08:26:00	26.1	55	0.4	28.25	31.0134337	27.7	8	Shade
11:42:00	31.1	43	0.6	36	43.285032	36.4	35	Shade
15:24:00	33.9	32	0.1	37.5	39.3483614	37.1	42	Shade
19:10:00	32.8	33	0.2	35	36.7547646	34.9	1	Shade
Open location near Piazza Italia								
08:30:00	26.1	55	1.2	29.25	36.8179489	28.3	394	Sun
08:32:00	26.1	55	1.5	30.75	43.0475731	30.3	392	Sun
11:36:00	31.7	41	1.8	41	64.5943898	44.2	74	Sun
15:30:00	34.4	30	1	41.75	55.3904796	43.7	666	Sun
19:06:00	32.8	32	0.5	35	38.0220887	35.1	19	Shade
Passageway near Maxi shop								
08:34:00	26.1	55	0.8	32.25	43.3105154	32.2	123	Shade
11:34:00	31.7	43	0.7	42	57.2780914	43.6	28	Shade
15:32:00	34.4	30	0.9	43.5	58.9646879	45.7	12	Shade
19:02:00	32.8	33	0.4	35	37.6481976	35.1	0	Shade
Under a tree near Kombinat caffee								
08:36:00	26.7	55	0.8	33	44.2389387	33.1	29	Shade
11:32:00	31.1	43	1	42.25	62.239683	44.7	72	Shade
15:36:00	34.4	30	0.9	41.5	53.9672294	43.2	600	Mixed shade
18:58:00	32.8	34	0.8	34.25	36.91465	34.3	8	Shade
Open area - soil/grass								
08:38:00	26.7	54	1.2	31.75	43.3585883	31.6	61	Cloudy weather
11:30:00	31.1	44	1.4	42.5	66.9372303	45.8	755	Sun
15:38:00	35	29	1.1	43.5	59.7345104	46.1	607	Sun
18:56:00	32.8	33	1.1	34.75	39.0331403	34.9	10	Mixed shade
Under a coniferous tree near Pharmacy								
08:40:00	26.7	54	0.8	32	41.6222395	31.9	0	Shade
08:42:00	26.7	53	0.7	29.25	33.7513365	28.6	1	Shade
11:24:00	30.6	45	0.8	36	45.4420941	36.6	3	Shade
15:42:00	35	29	0.7	43.5	56.0920235	45.1	17	Shade

18:52:00	32.8	33	1.1	34.5	38.2527376	34.6	3	Shade
Small square near Radio								
08:44:00	26.7	54	0.5	28	29.9230548	27.4	42	Cloudy weather
08:46:00	26.7	54	0.8	28.5	31.9855321	27.6	42	Cloudy weather
11:22:00	30.6	45	1.3	36.75	50.7290853	38	733	Sun
15:44:00	35	29	1.5	42.5	59.8255372	45.4	590	Sun
18:50:00	32.8	33	1	35	39.5468284	35.2	22	Shade
Under a tree on a path to Danube Park								
08:48:00	26.7	54	0.9	29	33.7271543	28.1	44	Shade
11:20:00	30	49	1.5	37.5	55.5859749	39.3	724	Mixed shade
15:46:00	35	30	1.2	45.5	65.8498328	48.9	614	Mixed shade
18:48:00	32.2	34	0.7	34.75	39.0208761	34.9	5	Shade
Under a tree in Danube Park								
08:50:00	26.7	54	0.5	30	34.7202583	29.6	68	Shade
11:18:00	30	46	1.3	38.25	56.3763716	40.1	791	Mixed shade
15:48:00	35	30	0.9	44.5	60.4591396	46.9	89	Shade
18:46:00	32.2	33	1.2	34.5	39.8090053	34.7	17	Shade
Near small lake in Danube Park								
08:52:00	26.7	54	1.3	30.25	39.0575717	29.6	470	Sun
11:16:00	30	48	0.9	36	47.166201	36.8	757	Sun
15:50:00	34.4	29	1	42.5	57.3433468	44.6	81	Shade or Cloudy weather
18:44:00	32.2	34	0.8	34.25	37.9974464	34.3	15	Shade
On a grass in Danube Park - open location								
08:54:00	26.7	53	0.9	32	42.293043	31.9	500	Sun
11:14:00	29.4	49	0.9	33.5	41.4386318	33.7	755	Sun
15:52:00	34.4	30	0.5	41.5	50.4109796	42.3	119	Sun
18:40:00	32.2	35	0.7	34.5	38.3690519	34.6	26	Shade
Under a tree over grass								
08:56:00	26.7	53	1.2	32.25	44.8832783	32.3	33	Shade
11:12:00	29.4	50	0.9	32.75	39.3272338	32.8	678	Mixed shade

15:54:00	34.4	33	1	43.25	59.2667742	45.6	133	Mixed shade
18:38:00	32.8	35	0.7	35	38.6862314	35.2	26	Shade
Over a path in the Danube Park								
09:00:00	26.7	54	0.6	30	35.2521219	29.5	72	Shade or Cloudy weather
11:08:00	30	47	1.6	35.75	50.6302237	36.9	95	Shade/Cloudy weather
15:58:00	33.9	33	0.6	42.5	54.2688473	43.7	72	Mixed shade
18:34:00	32.8	34	1.3	34.5	38.640561	34.6	17	Shade
Location near flowers in Danube Park								
09:04:00	26.7	55	0.6	29.75	34.6252241	29.2	26	Cloudy weather
11:04:00	29.4	48	0.8	35	44.8657231	35.5	770	Sun
16:00:00	33.9	34	0.6	43.75	56.9821489	45.2	613	Sun
18:32:00	32.8	35	0.9	34.5	37.8338295	34.6	28	Mixed shade
Under a tree near caffee in Danube Park								
09:06:00	26.7	55	0.4	30	34.1405908	29.6	37	Shade
11:00:00	29.4	48	0.7	31.25	34.4723977	30.9	47	Shade
11:02:00	29.4	47	0.4	31.25	33.5636524	31.1	66	Shade
16:02:00	33.9	32	0.3	43.75	52.6593152	43.9	37	Shade
18:30:00	32.8	34	0.1	34.5	35.4026924	34.4	3	Shade

Appendix II.c) Frequency (%) Shade/Sun from each group

	Frequency (%)			
Weather Condition	**d.xtree**	**d.utree**	**p.xtree**	**p.utree**
Sun	33.33	5.88	52.94	0
Cloudy weather	5.88	5.88	11.76	0
Mixed shade	1.96	23.53	5.88	29.41
Shade	56.86	64.71	17.65	64.71

Appendix II.d) Frequency (%) PET from each groups

PET Frequency (%)	**PET-NTS**	**PET-d.xtree**	**PET-d.utree**	**PET-p.xtree**	**PET-p.utree**
Extreme cold stress	0	0	0	0	0
Strong cold stress	0	0	0	0	0
Moderate cold stress	0	0	0	0	0
Slightly cold stress	0	0	0	0	0
No thermal stress	0	0	9	0	0
Slight heat stress	30	21	13	11	0
Moderate heat stress	19	25	31	41	61
Strong heat stress	23	21	22	23	15
Extreme heat stress	27	31	22	23	23