TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Diplomarbeit

# HEAT RELATED VULNERABILITY IN VIENNA IN THE CONTEXT OF CLIMATE CHANGE

ausgeführt zum Zwecke der Erlangung des akademischen Grades einer Diplom-Ingenieurin unter der Leitung von

Univ. Prof. Mag. Dr. Rudolf Giffinger
Univ. Ass. Dipl.-Ing. Robert Kalasek
E 280 – Department für Raumentwicklung, Infrastruktur- und Umweltplanung
Fachbereich für Stadt- und Regionalforschung

eingereicht an der Technischen Universität Wien
Fakultät für Architektur und Raumplanung

**HELENE STEINER**
0827075
Pasettistraße 29/1/13
1200 Wien

Wien, am 28.2.2015

## ABSTRACT

Heat is increasingly becoming a problem for human health due to climate change. This is particularly important for cities because of the urban heat island effect. The built-up structure has an influence on the urban climate. Therefore, heat is of interest for spatial planning. Information on the impacts of heat is necessary on a high spatial resolution to adapt to climate change.

This thesis investigates the heat related vulnerability in Vienna. The way people are vulnerable to heat was identified based on the state of research. These findings were converted to indicators to analyse the current situation in Vienna. Then, it was compared to the potential future development. Recommendations for urban planning can be derived from this information.

The concept of vulnerability examines the sensitivity of the population and location and the exposure by climate stimuli. Vulnerability is a relative term. It was calculated for each location of Vienna in contrast to the rest of the city. The sensitivity was measured by the population density, its age and sex composition and the supply of compensating areas and medical services. The exposure was defined by the average number of summer days per year. Additionally, the adaptive capacity is relevant for the examination of the future. In this study, it was defined by the ability of urban planning to implement adaptation measures. A GIS-based approach was used to examine the differences within the city. This thesis compares the current heat stress with the future development. Therefore, climate scenarios were used.

The results show that heat vulnerability is distributed unequally within the City of Vienna. Thus, measures of urban planning are needed. The consideration of heat in the planning process is therefore necessary.

## ZUSAMMENFASSUNG

Aufgrund des Klimawandels wird Hitze zunehmend zu einem gesundheitlichen Problem. Das betrifft aufgrund des Hitzeinseleffektes besonders Städte. Die bebaute Struktur beeinflusst das Klima einer Stadt, deshalb gewinnt der Faktor Hitze für die Raumplanung an Bedeutung. Für eine Anpassung an den Klimawandel sind räumlich differenzierte Informationen über die Auswirkungen von Hitze notwendig.

Die vorliegende Arbeit untersucht die Hitzevulnerabilität am Beispiel von Wien. Dafür wurde zuerst anhand bestehender Forschungen analysiert, inwiefern Menschen aufgrund von Hitze verwundbar sind. Davon wurden Indikatoren gebildet, um die aktuelle Situation in Wien zu analysieren. Diese wurde mit der möglichen zukünftigen Entwicklung verglichen. Daraus leiten sich potentielle Handlungsstrategien für die Raumplanung ab.

Das Konzept der Vulnerabilität stellt die Sensitivität der Bevölkerung und des Ortes der Exposition durch Klimastimuli gegenüber. Vulnerabilität ist dabei ein relativer Begriff. Die Verwundbarkeit einzelner Stadtteile wurde im Vergleich zur gesamten Stadt berechnet. Die Sensitivität wurde anhand von Bevölkerungsdichte, Alters- und Geschlechtszusammensetzung sowie der Versorgung mit Grünräumen und medizinischer Infrastruktur gemessen. Die Exposition wurde durch die durchschnittliche Anzahl an Sommertagen pro Jahr definiert. Für die Analyse der zukünftigen Entwicklung ist zudem die Anpassungskapazität relevant. Diese definiert sich durch die Fähigkeit der Raumplanung, Maßnahmen zu setzen. Es wurde ein GIS-basierter Ansatz verwendet um Unterschiede innerhalb der Stadt erkennen zu können. Diese Arbeit vergleicht die aktuelle Situation in Bezug auf Hitzestress mit der Entwicklung zum Ende des Jahrhunderts. Dafür wurden Klimaszenarien herangezogen.

Die Ergebnisse zeigen, dass die Hitzevulnerabilität in Wien ungleich verteilt ist. Deshalb sind Maßnahmen der Raumplanung notwendig. Dabei ist vor allem die Berücksichtigung von Hitze im Planungsprozess relevant.

# TABLE OF CONTENTS

# ABBREVIATIONS

BEV - Austrian Federal Office of Metrology and Surveying

EEA – European Environment Agency

GDP – Gross Domestic Product

IPCC – Intergovernmental Panel on Climate Change

LAI – Leaf Area Index: "is defined as the one sided green leaf area per unit ground area in broadleaf canopies, or as the projected needleleaf area per unit ground area in needle canopies" (Breuer and Frede 2003).

NASA – National Aeronautics and Space Administration (USA)

NDVI – Normalized Difference Vegetation Index

PMV – Predicted Mean Vote (index for thermal comfort)

UBA – Federal Environmental Agency (Umweltbundesamt)

UHI – Urban Heat Island

ZAMG – Central Institution for Meteorology and Geodynamics of Austria (Zentralanstalt für Meteorologie und Geodynamik)

# LIST OF FIGURES AND TABLES

# 1 INTRODUCTION

## 1.1 MOTIVATION

In the last decades, heat has been the most fatal natural hazard in Europe according to a report of the European Environmental Agency (EEA) published in 2010 about natural hazards in Europe from 1998 to 2009. This is mainly due to the heat wave in 2003 with over 70,000 fatalities. Additionally, the heat waves of 2006 and 2007 caused in total about 3000 deaths (EEA 2010, 9). In the context of climate change, this danger is about to become even more important. “Compared to the preindustrial level (end of the 19$^{th}$ century), mean temperature and the frequency and length of heat waves have increased across Europe” (EEA 2012a, 16). According to the EEA report of 2012 this trend is going to continue and temperature extremes are projected to have a major impact onto central and eastern Europe (including Vienna) in 2100 (ibid., 25). A study of Lung et al. suggests that heat stress related vulnerability could increase strongly in Central Europe (2013, 533). They suggest that this is in part caused by the ageing and thereby more sensitive population (ibid.). At the same time the urban areas of Europe, including Vienna, suffer already a high level of heat stress according to this study (ibid., 527f).

Compared to other hazards heat waves caused a relatively minor economic loss: the total of all extreme temperature events included in the EEA report led to overall losses of EUR 9.962 billion while the total of all natural hazards were estimated to cause economic loss of EUR 148.831 billion between 1998 and 2009 (EEA 2010, 9).

This thesis concentrates on the effects of heat stress on human health as the main adverse effect of heat. Furthermore, the measures to avoid loss in property due to heat differ significantly from the measures to avoid health problems and deaths.

Vienna is a growing city. This can be seen in the demographic development: the population has been growing since the end of the 1980s and this trend is expected to continue (STATISTIK AUSTRIA 2013; STATISTIK AUSTRIA 2014). The urban development influences the urban climate (see section 2.3.2 Urban Heat Island Effect). This is particularly important for a growing city because of the high demand of use and conflicting interests. Therefore, the potential heat stress is of interest for urban planning.

The starting point of this study is the current situation to show how the problem of heat stress is distributed over Vienna in the moment. Additionally, it is a reference point for the future development to detect areas with strong changes, which are of interest for adaptation strategies. Adger suggests “that climate change impacts will substantially increase burdens on those populations that are already vulnerable to climate extremes” (2006, 273). Hence, the current situation of heat stress is important to set the context.

The aim of this thesis is to detect areas in Vienna that are vulnerable to heat and to provide suggestions for spatial planning where adaptation measures should be taken. The role of spatial planning in dealing with heat stress is important due to the influence of settlement structures on heat and due to the possibilities to handle the effects of heat stress.

## 1.2 Research Questions and Methodology

The research questions of this study are:

- In what way are people vulnerable to heat stress in cities?
- Which areas of Vienna experience heat stress at the moment? How might the situation of heat vulnerability change in the future due to climate change and demographic change, and what are the possible adaptation strategies to avoid these effects?

The hypothesis that leads this research is that the risk of heat stress related vulnerability is not equally distributed over Vienna and that it will most probably increase in the future due to the changing circumstances.

### 1.2.1 Scenario Analysis

In order to describe the impact of heat on Vienna, scenarios of the global climate change will be taken into account.

Scenarios are used to show possible developments of a phenomenon in the future. The scenario technique does not focus on the past development of a phenomenon, but on its interactions with and dependencies on other factors (see Gausemeier, Fink, and Schlake 1995, 83–90; Wilms 2006, 72–73).

Thus, a first important step for scenarios is to identify key factors that influence the phenomenon of interest. The attempt is made to explain the object by these factors and their connections. The second step is to illustrate the possible future developments of these factors. The combinations of all possible developments of all factors result in the total of possible scenarios. Only consistent scenarios are used for further processing, i.e. scenarios without internal contradictions of their factors (Wilms 2006, 72, 216–217).

The storylines of different scenarios can be contradictory as not more than one future will come true (Wilms 2006, 69). Scenarios are a way to deal with an uncertain future. They do not show one exact picture of the future world but possible development processes. By increasing the knowledge about possible developments the future can be influenced in a favourable way (Wilms 2006, 76).

This study is based on scenarios of climate change because the process of global warming is dependent on a variety of factors and cannot be explained by the past development of the global climate alone. Furthermore, global warming can be influenced by human decisions due to the role of anthropogenic activities in climate change. The impacts of rising temperatures on a local level can thereby only be sufficiently approached when considering the different possibilities for the future development. A great part of changes of the atmosphere cannot be prevented on a local level. As a consequence, when trying to deal with potential impacts different pathways of future developments should be considered.

### 1.2.2 Operationalisation

The aim of this thesis is to measure vulnerability to heat stress. The term “vulnerability” will be defined in chapter 2 (Theoretical Background) to limit the scope of interpretation. Indicators will be used to approximate this term.

Indicators can help to illustrate terms that are not evident (Littig and Grießler 2004, 79). Instead of measuring a phenomenon directly indicators are defined which describe the phenomenon sufficiently. Indicators should be derived from the theory of the topic (Friedrichs 1990, 80). The selection of indicators can thereby be legitimated (ibid.) as they are then based on terms of current research. Thus, indicators also provide the connection between the conceptual framework and the observational level (ibid.).

This concept is implemented in this research in the following methodology:

The first research question[1] is approached by literature research to find out the state of science on who is in what way and why vulnerable to heat stress. This includes the medical and social factors determining the heat stress human beings face on one side and the aspects of microclimate which lead to the specific heat exposure of cities on the other.

The gathered information will then be transferred to indicators to measure the determinants of vulnerability in Vienna. The possible changes of the indicators describe the future scenario. This study uses already existing data because it is not possible to collect high resolution data for the whole City of Vienna in the scope of this study.

This thesis uses methods based on Geographic Information Systems (GIS), which provide the possibility to include a spatial aspect. Data with a high spatial resolution will be needed to map the heat stress. First, the status quo will be analysed. This information will then be used as a reference point (baseline scenario) for the comparison with the future scenario. Thereby, future areas of interest for adaptation to heat stress can be identified. These steps answer the second and third research question[2].

The outcome of the research will be the detection of hotspots of future heat stress within the city of Vienna in comparison to the situation nowadays.

For spatial calculations ArcGIS 10.2 and Python 2.7 are used. Statistical calculations are made in R 3.0.1.

## 1.3 Structure

The first part of this thesis deals with the theoretical basis of vulnerability. Therefore, the context of climate change, the particular circumstances of heat in cities and the health problems related to heat are explained. Different concepts of assessing climate change are discussed to form a framework for this thesis. The terms *sensitivity*, *exposure*, *impact* and *adaptive capacity* are explained in this chapter.

The chapter “Case Study Vienna” presents the practical approach to heat stress in this city. Therefore, indicators are derived from the literature. They are limited by the data availability. The focus of adaptation is thereby the context of spatial planning. This chapter explains the combination of the different aspects of heat stress.

In the end, the results of this study are illustrated and discussed. Recommendations for spatial planning are derived from the results of heat stress in Vienna.

[1] “In what way are people vulnerable to heat stress in cities?”

[2] “Which areas of Vienna experience heat stress at the moment? How might this situation of vulnerability change in the future due to climate change and demographic change, and what are the possible adaptation strategies to avoid these effects?“

# 2 Theoretical Background

This thesis is based on the concept of vulnerability to climate change. In this chapter, the importance of climate change for spatial planning will be discussed. Then, the possibility of how to assess heat stress will be argued. In the end, the problems of heat stress in the context of human health and the urban heat island (UHI) effect will be explained.

## 2.1 Climate Change

In contrast to weather, climate is defined as the entity of weather events (Stock 2013, 19). It is the system of processes within the atmosphere, the interior of the earth and the solar system (ibid.). Thus, there is a difference between single events and changes in the entire climate, but they are connected as weather events depend on the climate.

Different data certify a trend of long term global warming for example from the UK Meteorological Office, the Hadley Centre/Climatic Research Unit (HadCRU) and the U.S. National Climatic Data Center, U.S. National Aeronautics and Space Administration (NASA). The ten hottest years since the observations started (in 1850) have occurred in the last 15 years (Stock 2013, 15).

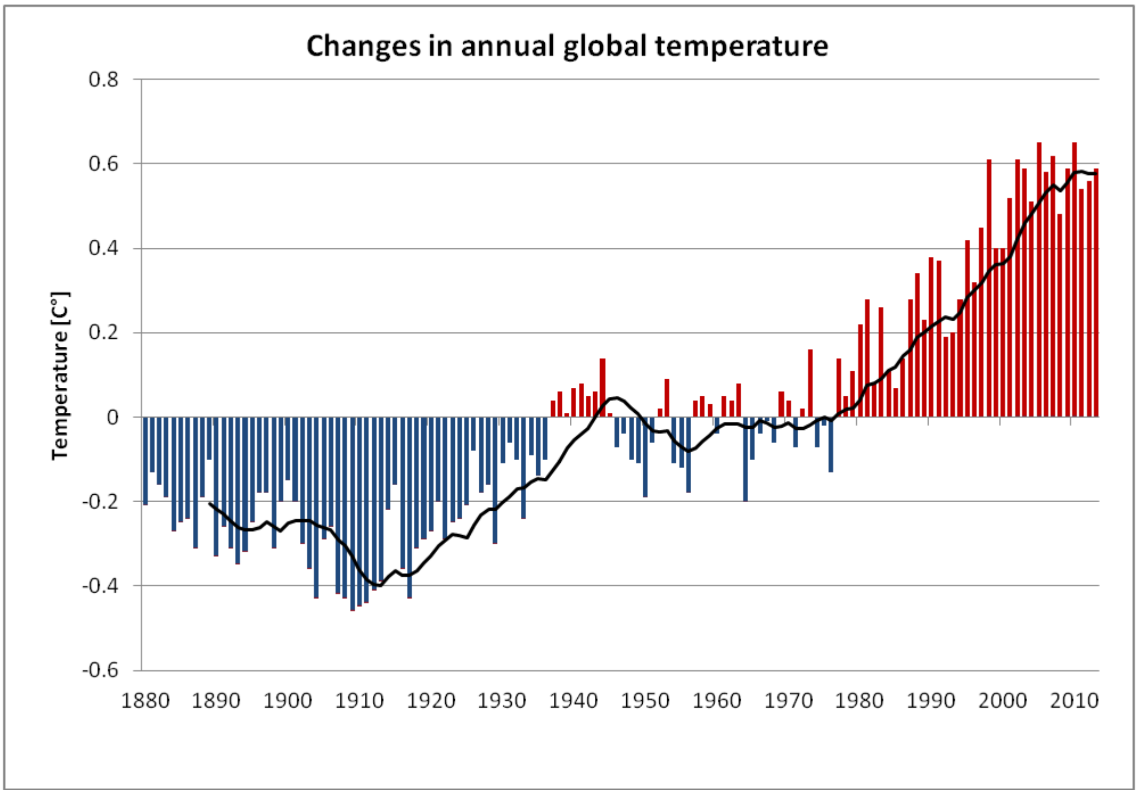



**Figure 1 Global Land-Ocean Temperature Index in degrees Celsius. The trend line shows the 10-year mean. 0 is the average of the base period 1951-1980 (source: own illustration, data: NASA 2014: online).**

Figure 1 shows the deviation of global annual mean temperature from the base period 1951-1980. The trend line averages the temperature of ten year periods. Although there are many years that don't follow the trend of rising temperatures, there is a trend visible especially in the last 50 years. Regional temperatures can differ significantly from the global trend and have much more deviation between years (Stock 2013, 16f). Thus, a regional differentiation of climate change impacts is necessary.

Differences within the years are not only and not always due to greenhouse gas emissions but also due to other climate factors: changes of the earth orbit, the axis of the earth and in the solar activity, but also changes in the relation of reflection and absorption of the sun light in the atmosphere and on the earth's surface (the albedo, which differs due to land use and clouds) have an influence on the climate. These factors interact: a change in one factor can reinforce or reduce other factors (Stock 2013, 19f).

The climate has always been subject to changes in the history of the earth. Since the industrialisation, human activities have changed the composition of the atmosphere (EEA 2012b, 49f). The current warming, which is mainly due to the changed atmosphere (concentration of greenhouse gases like water vapour, $CO_2$ and methane) is especially a problem due to its speed: ecosystems need time to adapt (Stock 2013, 21). This process is about to continue in the future due to human activities (EEA 2012b, 51). Thus, strategies are needed to deal with climate change. They can be differentiated into two groups: mitigation and adaptation.

### 2.1.1 Mitigation

The climate change includes warmer temperatures which lead amongst other impacts to changes in precipitation, rising sea level and altered land cover (see e.g. Rahmstorf and Schellnhuber 2012, 54ff). A major problem within these changes are extreme events and their frequencies. The changes are assumed to be associated with the anthropogenic climate change and thereby supposed to increase in the future (Stock 2013, 25). Examples for extreme weather events are heavy rain and heat waves. The latter is of special interest for this thesis. The possibility of increasing frequency of heat waves is one reason to look closer at the impacts (see section 2.3 Heat Stress).

These negative effects necessitate mitigation, which is „an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases“ (IPCC 2001a, 379). Mitigation can be defined as the attempt to reduce or even stop the climate change. The mitigation needs to be global because the climate is affected on a global scale. In the last decades, these attempts were not yet sufficient to stop the climate change.

On the other hand, effects of the climate change take a regional impact as they differ dependent on the location (Füssel and Klein 2006, 313). This fact raises questions of equality as some regions are significantly affected by climate change impacts while other regions may not be affected adversely at all. Adger suggests that these effects will substantially increase burdens on those groups that are already vulnerable to climate extremes (Adger 2006, 273). Therefore, the adverse effects have to be approached directly on a local level parallel to the attempt of mitigation.

### 2.1.2 Adaptation

The term adaptation can be defined as „adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities“ (IPCC 2001a, 365).

Adaptation to climate change has become necessary as some amount of the effects of climate change is not preventable any more (Füssel and Klein 2006, 304). Stock for example estimates an increase in global temperatures of approximately 0.9°C in comparison to the preindustrial level (2013, 25). Therefore, the affected systems and regions need adaptation to the adverse effects of this climate change. A shift from mitigation to adaptation in climate change research is already noticeable (Birkmann 2013, 19).

This does not mean that mitigation was given up but additional measures are needed to moderate the effects also on a local level. On one hand the adaptation to climate change can also reduce the risks of general climate variability that can already be observed (Füssel and Klein 2006, 304). On the other hand adaptation and mitigation can support each other. Schmidt and Baltes suggest measures to decrease the heat island effect and thereby reduce energy consumption by air conditioning (Schmidt and Baltes 2012, 156f). However, as a reduced heat island also influences the necessity of heating and can thus increase the energy consumption, such measures can also be negative for climate change mitigation. This area of conflict is especially obvious in the context of the concept of compact city and the problem of heat island. This issue will be discussed in the end of this thesis.

The effects of climate change have to concern spatial planning as they are localised and differ spatially. In the context of the distribution of land uses, services and infrastructure and the city development the consideration of future climate stimuli can help to improve these decisions. Spatial planning is per se a discipline that considers the future due to the fact that every planning decision will influence the future. In this matter spatial planning has to consider the potential future development, which includes effects of climate change. As the future climate changes are uncertain it is getting more and more important to think in scenarios (Greiving and Fleischhauer 2012, 32). Therefore, the basis for spatial planning decisions are different scenarios and measures trying to deal with the ones that are most likely. Another attempt to meet this uncertainty is to focus on no-regret or low-regret strategies (ibid.). These strategies are beneficial even in the case of no climate change. However, spatial planning always deals with divergent interests. A beneficial measure for some might be harmful for others. Thus, every measure and strategy always includes a political component.

## 2.2 Vulnerability

The Intergovernmental Panel on Climate Change (IPCC) defines the term vulnerability as: “[t]he degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (IPCC 2001b, 388). This is the definition used by the IPCC 3rd assessment report. It is presented here because a huge amount of vulnerability research (including this thesis) is based on or uses IPCC results. The definition of vulnerability can be described by the equation

$$V = f(E, S, AC)$$

V is the vulnerability, E is the exposure, S is the sensitivity and AC is adaptive capacity. These terms will be examined below to conclude with the definition relevant for this thesis. The exact way they are measured will be described in chapter 3 Case Study: Vienna.

Vulnerability describes a future situation due to the inclusion of adaptive capacity, which can be used in the future.

### 2.2.1 Exposure

Exposure is "the nature and degree to which a system is exposed to significant climatic variations" (IPCC 2001b, 373).

Thus, it describes the physical component of vulnerability. Exposure depends on the level of climate change as well as on the location because the impacts of climate change vary around the world (Füssel and Klein 2006, 313). It includes the variations influenced by the global climate change as well as non-human caused exposure of climate.

There are no differences in the effects for the exposed system whether a single climate variation is due to the anthropogenic climate change or not. Overlooking the entire climate system single weather events cannot be traced back to just one reason. Rahmstorf and Schellnhuber compare this fact to the increased probability that smokers get lung cancer: for an individual case it is difficult to detect the smoking as the reason for cancer because there are many influences (Rahmstorf and Schellnhuber 2012, 70). Therefore it will not be differentiated between the reasons of a climate stimulus. Examples of measuring the exposure are indicators like summer days and tropical nights for heat exposure (see e.g. Lung et al. 2013) or models to simulate floods (see e.g. Greiving 2013, 290).

### 2.2.2 Sensitivity

"Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise)" (IPCC 2001b, 384).

Sensitivity thereby describes components of the system (e.g. the society, a city or ecosystem) and how they might be affected by climate change. It provides the possibility to include social aspects into the analysis of climate risks. Many studies use indicators to estimate the sensitivity to a specific hazard as for example the percentage of elderly people (see e.g. Lung et al. 2013; Richter 2010) or indicators of the settlement structure like the population density (ibid.).

This definition of sensitivity allows including positive effects on the system. In contrast to the term "susceptibility", which is also often used in the context of vulnerability, sensitivity is more neutral (Birkmann 2013, 25). Birkmann uses "susceptibility", because it characterizes the predisposition to suffer harm in the case of a hazard (ibid.). As climate change can also have positive effects (see 2.1 Climate Change), the term "sensitivity" is used in this thesis. In assessments which deal with different sectors individually or (like this thesis) deal only with one aspect it can be differentiated directly between positive and negative aspects of climate change. This thesis deals with the harm and fatalities through heat, but the interdependencies with positive aspects will be discussed in the end.

The important difference between exposure and sensitivity in this thesis is that the sensitivity can be addressed on a local level while the exposure depends on the global climate. As Lung et al. put it, exposure is driven by climate indicators while sensitivity is driven by socio-economic and land use indicators (2013, 523). Sensitivity shows the influence of human actions on vulnerability. It is not always easy to differentiate between exposure and sensitivity as local climate is influenced by land use. This is especially the case for the urban heat island (UHI) effect: the temperature is strongly influenced by the settlement structure and the amount of vegetation (Harlan et al. 2006, 2855) (see 2.3.2 Urban Heat Island Effect).

### 2.2.3 Impact

Impact can be described as the "consequences of climate change on natural and human systems" (IPCC 2001b, 375). It is the combination of exposure and sensitivity (Füssel and Klein 2006, 319; Lung et al. 2013, 523) and shows the potential problems or benefits due to climate stimuli for a system. There is for example no expected harm for human lives if a heat wave occurs on an unpopulated area. If people are not sensitive to heat they will most likely not be harmed by a heat wave. This example shows the importance of spatial differentiation to estimate the impact.

The current impact can be compared to the future vulnerability, because it is the situation in which all possible adaptation is already applied. It is thereby useful to compare the impact of the baseline scenario with the vulnerability of the future scenarios.

### 2.2.4 Adaptive Capacity

Adaptive capacity is defined by the IPCC as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2001b, 365).

As described above, some amount of climate change is most likely not preventable anymore and therefore needs adaptation. In comparison to adaptation the term "adaptive capacity" is only the theoretical potential of people or systems to adapt to climate change. Between adaptive capacity and adaptation is the need for the human factor to implement the measures. The probability of this realisation cannot be done in the scope of this thesis.

Due to this difference this thesis can be ranked among the "2nd generation of vulnerability assessments" in contrast to the first generation. This categorisation is made by Füssel and Klein (2006, 319), who describe four prototypical stages of vulnerability assessments (they are shown here only in their main differing aspects):

- Impact assessments: The output is the potential impact of climate change. This is defined by the exposure to climate stimuli and the sensitivity of the system (Füssel and Klein 2006, 312ff). Thereby, it does not include the possibility to adapt to the impact.
- Vulnerability assessments: They include the relevance of impacts for the society and the potential adaptation (ibid. 2006, 315). The two generations differ in the understanding of adaptation as mentioned above.

- Adaptation policy assessments: They address information needed for policy-makers for adaptation (ibid. 2006, 321). This is not the main goal of this thesis, thus, this form of assessment is not used.

Adaptive capacity can be distinguished in public and in individual capacities. Financial adaptive capacity in this sense could be divided in the public budget and the financial resources of the population. The adaptive capacity can have an influence on the future sensitivity (in the case of realised adaptation). Therefore, it is important to clearly distinguish these terms. The focus of this research is on the spatial planning level of adaptive capacity. The operationalisation will be explained in section 3.2.

The concluding assessment is shown in Figure 2. All arrows show an important influence (not differentiated whether positive or negative). The boxes with grey background are the parts dealt with in this thesis.

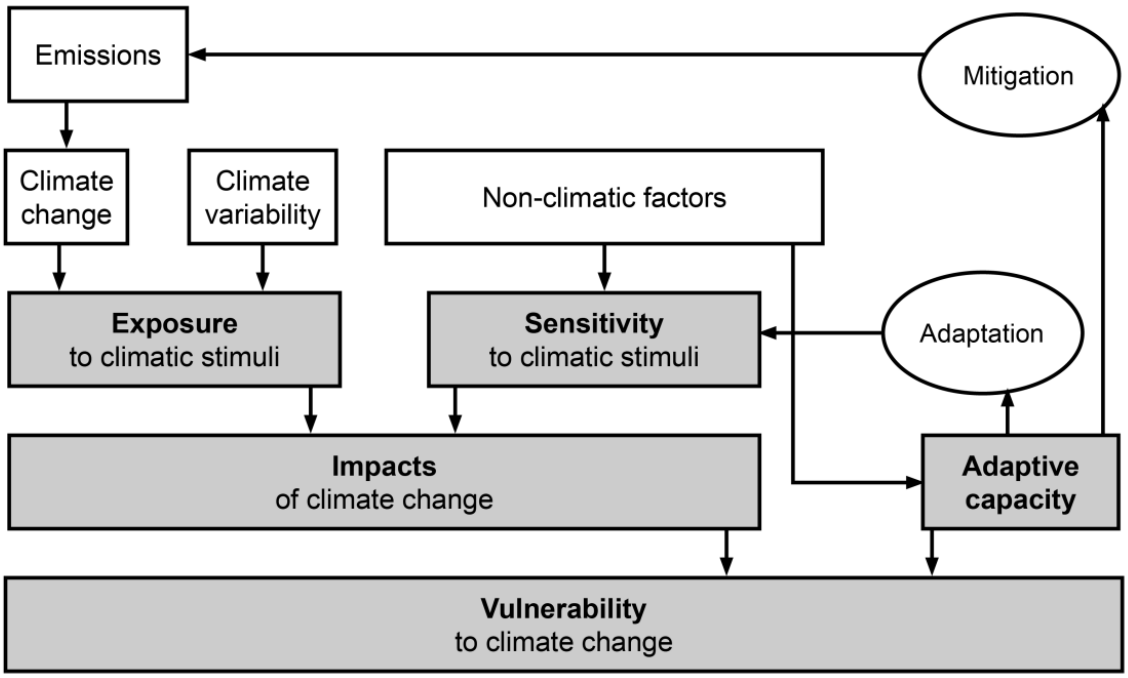



**Figure 2 Vulnerability assessment (source: own illustration based on Füssel and Klein 2006, 319)[3]**

The definitions presented above suggest that a high value of exposure and sensitivity contributes to an increase in vulnerability, while a high value of adaptive capacity contributes to a decrease in vulnerability. Accordingly, for the calculation of vulnerability there is a positive mathematical connection between exposure (E) and sensitivity (S), respectively, and vulnerability (V) and a negative connection between adaptive capacity (AC) and vulnerability (V). This leads to the following equation:

$$V = S * E - AC$$

[3] This is a simplified and adapted version of the figure and explanation by Füssel and Klein 2006. Following parts were changed: adaptation in this thesis is used as a consequence of adaptive capacity. For simplification, exposure is shown as influenced only by climate and not by non-climatic factors. Of course there are always interdependencies but for this assessment it is useful to reduce them to the most significant influences. Furthermore, adaptation is shown in an own circle, but it is also a non-climatic factor. It is mentioned explicitly to show its interdependencies in the assessment.

This equation allows the possibility of adapting completely to the impacts of climate change. Negative values of vulnerability indicate either a beneficial impact (suggesting that the climate change has positive effects in that particular case) or an adaptive capacity which exceeds the adverse effects of the impact. The input of exposure, sensitivity and adaptive capacity will be limited to limit the range of the vulnerability. However, this function contains an implicit weighting of the parameters. This is only an approximation because of the limited knowledge of their interdependencies.

### 2.2.5 Resilience

Another concept, which is often mentioned in the context of climate change in general and vulnerability in particular, is resilience. Adger defines the term in the context of socio-economic systems as "the magnitude of disturbance that can be absorbed before a system changes to a radically different state" while vulnerability is defined in negative terms (2006, 268). Sometimes the term is also used synonymously with adaptive capacity: resilience as adjustments and preparation for hazards (Pelling 2003, 48).

In contrast to the vulnerability concept, resilience emphasizes the importance of crises and stressors. According to this concept, stressors can "provide windows of opportunity for change and innovation" (Birkmann 2013, 33). It can be understood as the ability not to be harmed in the case of a hazard, but also as the ability to recover after a hazard (Birkmann et al. 2013, 212). The focus thereby is the time that is needed to recover and the innovations that can be used.

The vulnerability approach is more appropriate in the context of the possible fatalities of heat waves as it provides the possibility to focus on the future adaptation. This seems to be a useful approach for this thesis. Nevertheless, it should be kept in mind that a city with low vulnerability is also a resilient city.

### 2.2.6 Summary

The concept of vulnerability can be connected to spatial questions as its main focus is to find local effects of climate change. Its strength is to include social aspects in risk assessments. The time frame is relevant due to the focus on climate change. Vulnerability assessments depend on future scenarios that include uncertainties because the mitigation of and the adaptation to climate change are long-term issues. Vulnerability is a relative term in this context (cf. Füssel and Klein 2006, 317). It provides the possibility to compare one location with others or the situation of today with the future. It is not applicable to quantify the actual risk.

## 2.3 Heat Stress

The term "heat stress" is used to describe a situation when the body fails to control its internal temperature. It occurs due to the air temperature and humidity, but also the work rate, and the clothing. In severe cases a symptom can be a heat stroke which can lead to death if not detected in an early stage (HSE UK 2013, 1–2).

A definition of "heat wave" is presented here because this term often occurs in the context of heat stress (in many studies about mortality due to heat stress mainly heat waves are considered): "Heatwaves are defined as three days during which the daily maximum temperature is ≥ 30.0 °C. The heatwave persists as long as the average maximum temperature of the whole period remains above 30 °C and the daily maximum temperature never drops below 25 °C" (Kyselý 2002, 35; as cited in Hutter et al. 2007, 225). It was written by Kyselý in a study about Prague and was then used by Hutter et al. for a study on heat wave related mortality in Vienna, because of its suitability for Middle European climatic conditions.

### 2.3.1 Influence of Heat on Human's Health

The WHO suggests the following factors, which increase the risk of heat illness:

- "Factors affecting behaviour: physical or cognitive impairment, psychiatric illness, infants
- Increased heat gain: exercise, outdoor activity, medications
- Factors influencing cardiac output: cardiovascular disease, medications
- Factors reducing plasma volume: diarrhoea, pre-existing renal or metabolic disease, medications
- Factors affecting sweating: dehydration, ageing, diabetes, scleroderma, cystic fibrosis, medications" (2009, 4; adapted from Bouchama 2007). [4]

Air temperature is not the only parameter that has an effect on these factors. Muthers et al. use a model which additionally includes air humidity, wind speed, short and long wave radiation into the calculations of mortality risk as they influence physiological reactions of humans (2010, 526).[5]

A consensus exists that elderly are at special risk of dying due to heat (see e.g. Hajat and Kosatky 2010, 755; Bouchama A et al. 2007, 2173). However, different age groups are used to describe this fact. Baccini et al. identified for example a stronger association of temperature with mortality after the age of 74 years (2008, 718) while Hajat and Kosatky see an increase in risk for those aged 65 years or more (2010, 755). These differentiations might also be due to the available data.

Hajat and Kosatky derived a model from a meta analysis of multicity researches around the world on heat related deaths. It includes the increase in population density, decreasing total gross domestic product (GDP) of a city and the increasing percentage of the inhabitants aged 65 or more to explain the slope of deaths according to temperature (heat slope) (2010, 757). The population density may be an indicator for increased temperatures in urban areas (see 2.3.2 Urban Heat Island Effect) while the financial situation is important for the access to air conditioning (Hajat and Kosatky 2010, 758). The financial situation probably influences the sensitivity to heat on multiple levels for example on the availability of high quality housing. The meta analysis of Bouchama et al. on the other hand identified "being confined to bed", "not leaving home daily", "being unable to care for oneself" and medical conditions as associated with the risk of death during a heat wave (2007, 2173). Furthermore, some studies suggest that social isolation may increase the risk (Huang et al. 2011, 1681; Stafoggia et al. 2006, 315; Bouchama A et al. 2007, 2173). Social isolation is measured in different ways in these studies (ibid.).

[4] For detailed medical information on why elderly people are at risk to die from heat see Flynn et al. (2005).
[5] The basis of this model can be found in Höppe (1999).

In summary, a rank of medical but also social factors influences the sensitivity to heat. The differentiation of these factors into medical or social is not always clear as they influence each other. This is particularly the case for the presumable higher sensitivity of women, which was found by Muthers et al. for Vienna (2010, 528) and Stafoggia et al. for four Italian cities (2006, 315). It is not certain whether this correlation is due to medical predisposition of women in general or due to a social situation like different working conditions of men and women.

The heat threshold, which is defined as the temperature above which a significant rise in mortality risk can be observed, depends on the location: in areas with higher average summer temperatures, this threshold is also higher compared to areas with lower temperatures (Hajat and Kosatky 2010, 753f). Baccini et al. calculated this temperature for 15 European cities: the overall threshold was 29.4°C while for north-continental cities (Ljubljana, Stockholm, and Zurich) it was only 22°C (2008, 713). This suggests an acclimatisation of the population over time. However, it might also be influenced by different standards of health care.

White-Newsome et al. suggest differences in heat exposure between outdoor and indoor temperatures due to the building quality, the orientation and the city location (White-Newsome et al. 2012, 26). Indoor temperatures can thereby exceed the outdoor temperatures (ibid.). Thus, people who cannot leave their home are at special risk of heat stress.

### 2.3.2 Urban Heat Island Effect

The Urban Heat Island (UHI) effect is defined as the difference in temperature between an urban area and its rural surroundings. It occurs due to the built-up area in a city, which causes changes in the surface albedo, the evapotranspiration and the air ventilation. Additionally, anthropogenic heating plays an important role (Taha 1997, 99–100; Grimmond et al. 2010, 251).

The albedo defines the amount of the reflected sun energy. Urban albedos are normally between 0.1 and 0.2. It differs due to the material of buildings and can be increased for example with light building colours (Taha 1997, 100–101).

Evapotranspiration is the amount of water emitted to the air in form of vapour by transpiration. The main elements for evapotranspiration are soil and vegetation. It is reduced due to sealed surfaces. The more vegetation an area has (which is responsible for a high amount of evapotranspiration) the lower the temperature will be above this area. The impervious surfaces in cities lead to a fast runoff of water, which then cannot be used for evaporation in the city. This circumstance is seen as the major factor for the increasing daytime temperatures within urban areas (Taha 1997, 101). This was measured for example by Dobrovolný in Brno; she found a negative correlation of the land surface temperature and the Normalized Differenced Vegetation Index (NDVI) (Dobrovolný 2013, 95).

Anthropogenic heating and heat waste is produced by energy consumption. It derives from the energy use in buildings, transportation and industry. The heat from motor-driven vehicles has its effects directly within the city; however, the emissions from energy consumption in buildings and production also have an emission at the source of energy production depending on the way of production. Thermal power plants have a different heat emission than water power plants (Grimmond et al. 2010, 254).

The urban structure influences the heat island in mainly two ways. It determines the wind directions and thereby the possibilities of air exchange between cooler (especially rural) and hotter areas (Morris, Simmonds, and Plummer 2001, 173). Additionally, the height of buildings and width of streets (measured for example with the sky view factor) determines the heat release during the night: heat is trapped in high, narrow street canyons (Grimmond et al. 2010, 253).

Spatial planning can strongly influence the UHI. In the short and medium term it can change the rate of evapotranspiration with the reduction of sealed surfaces and the increase of vegetation. In the long term it can change the urban structures. Additionally, reforestation projects are possible in a longer time frame. These changes always have to be considered in relation to not encourage urban sprawl as such a development could also have negative effects on the UHI. While a lower building density and higher amount of vegetation have a cooling effect on the urban climate, an increase in traffic can for example intensify the anthropogenic heating. These influences of spatial planning on the UHI define the scope of this thesis.

# 3 Case Study: Vienna

Heat stress is a challenge particularly for growing cities because of the high pressure on land use. Inner development supports a higher building density and reduces the probability that undeveloped areas can be converted to parks. Urban sprawl, on the other hand, may destroy areas of fresh air production. All these developments have an influence on the city climate. The population of Vienna is almost continuously growing since the end of the 1980s[6]. Statistik Austria suggests that this trend is also about to continue for the next decades (2013). Thus, heat stress is of special interest for Vienna.

Figure 3 shows an aerial image of the City of Vienna. The urban and green areas, water bodies and agricultureal land are observable. The importance of this structure for the urban climate will be shown in the following section.


**Figure 3: Aerial image of Vienna (Stadt Wien 2011a).**

## 3.1 Heat Stress in Vienna

Vienna has an average midsummer temperature (July and August) of around 20°C. The temperature is not equally distributed; the temperature profiles of the weather stations differ within Vienna (see Figure 4: top panel). The mean summer temperature of the last 20 years (see Figure 4: down panel) shows a strong variation between the different summers, especially

[6] This data is according to the population statistic of Statistik Austria from 2014.

during the great heat wave of 2003 with an average summer temperature of 20.26°C (ZAMG 2013a; ZAMG 2002).

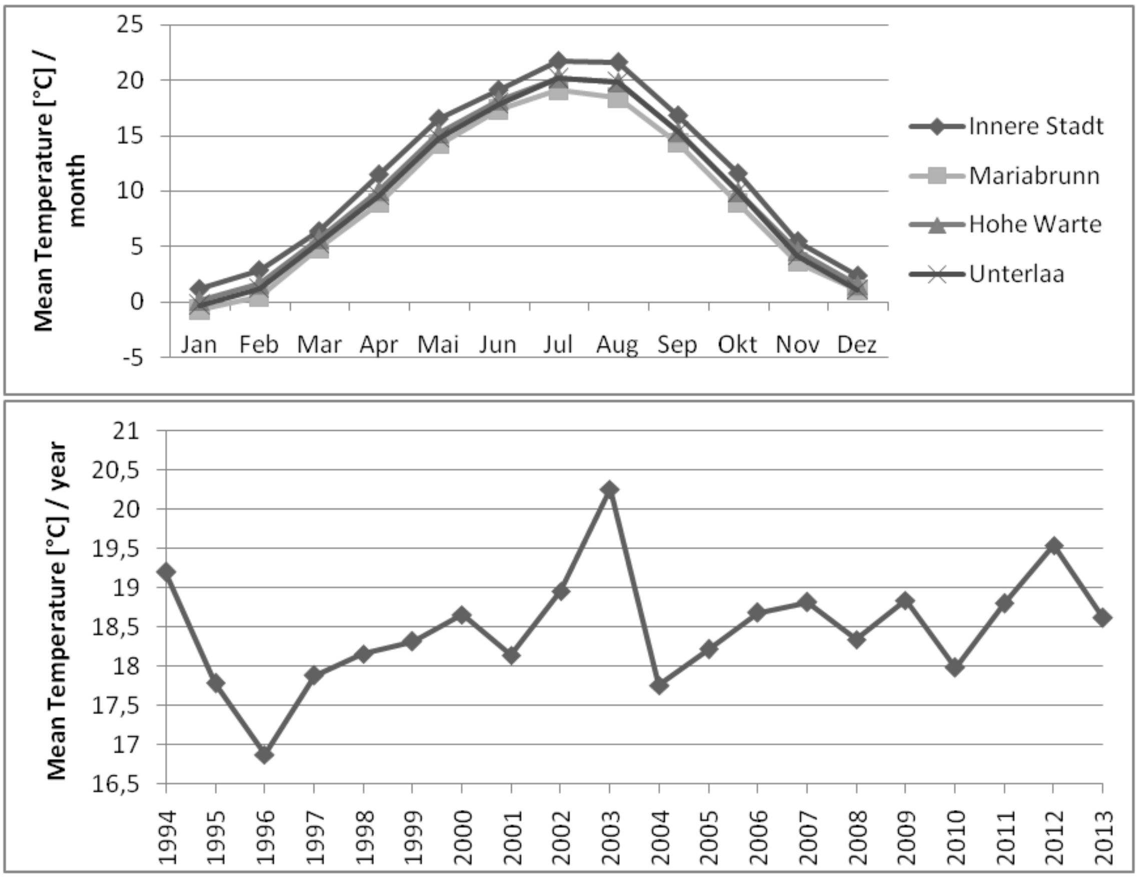



**Figure 4: Temperature in Vienna. Top panel: Mean Temperature [°C] from 1971-2000. Down panel: Mean summer (May - September) temperature (station Hohe Warte) from 1994 to 2013 (source: own elaboration; data: ZAMG 2002; ZAMG 2013a).**

The trend of the last 30 years shows an increase in temperatures. During this time, the UHI (urban heat island) intensity was relatively constant (Mahdavi, Kiesel, and Vuckovic 2014, 509). The UHI in Vienna has its strongest intensity during the night with a difference in temperature of about 3K (ibid.). However, during the day the UHI can even be negative (ibid.). In other words, during the day it is often warmer in the surroundings than in the city. This might be due to the increased shadowing by buildings in urban areas in contrast to natural land.

During the heat wave of 2003 180 people died from the consequences of heat stress in Vienna (Hutter et al. 2007, 225–226). Although these are relatively few deaths compared to other parts of Europe that were more affected by the heat wave as for example France, it still shows that the problem of heat stress exists in Vienna. From these 180 deaths Hutter et al. suggest that 130 could have been prevented (ibid.)[7]. Thus, future adaptation to heat stress is an important issue for Vienna. Elderly people have a higher risk to die from heat stress in Vienna: 80% of the people who died during the heat wave of 2003 were aged 65 and above (ibid.).

[7] These 130 deaths are not due to harvesting (Hutter et al. 2007, 226). Harvesting describes the situation that people die due to an event but would most probably also have died without this specific event within some days. This is to say that for example after a heat less people die than normally.

The distribution of heat stress is shown in detail in Figure 5: it shows the average number of summer days in the period of 1971-2000 with a spatial resolution of 100x100m based on a model to simulate the microclimate. Summer days are defined as days with a maximum temperature of ≥25°C (Žuvela-Aloise et al. 2013, 4).

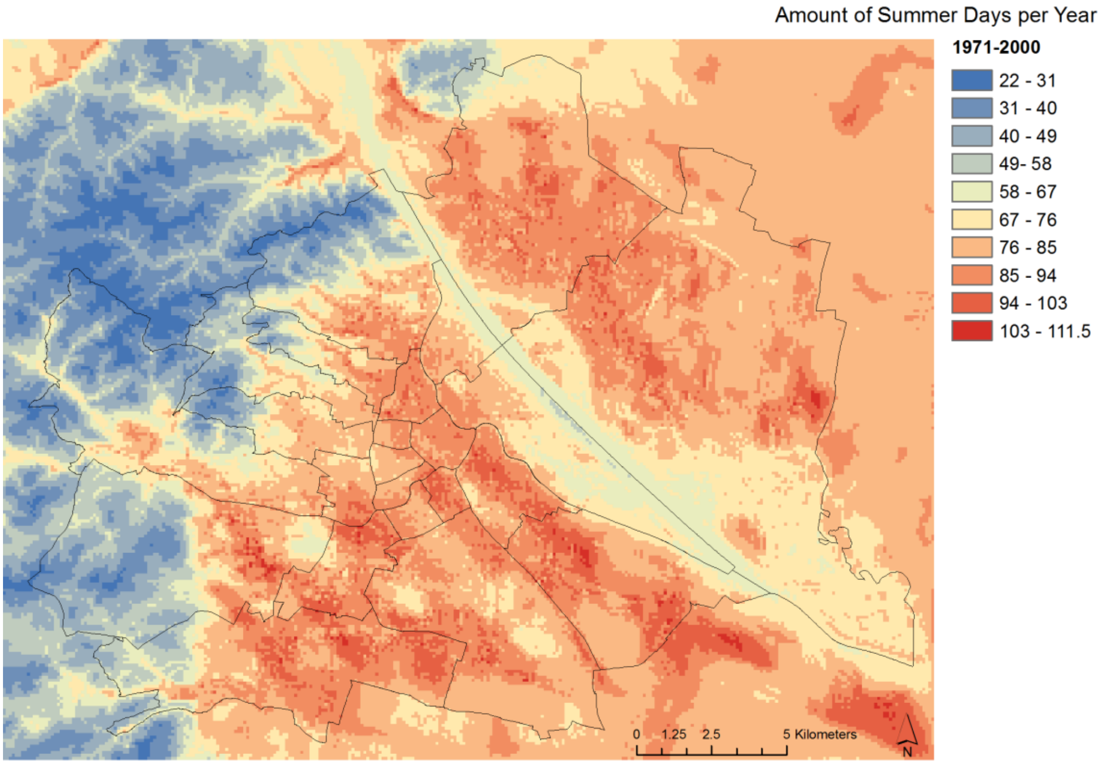



**Figure 5 Average number of summer days in Vienna between 1971 and 2000 (source: own illustration; data: ZAMG 2013b).**

The map shows strong variations within the city not only due to the main green areas and water bodies (Wienerwald, Danube River, Prater and the mountains in the north) but also within the urban areas of Vienna. These differences exist because of the variety of factors which contribute to an urban heat island (see section 2.3.2 Urban Heat Island Effect).

Urban climate depends on land use, amongst others; however, strong deviations can be seen within the land use classes. Figure 6 shows the differences in the number and deviation of summer days in the different land use classes of Vienna. The number of summer days is the highest in urban areas. Nevertheless, there are also differences within these areas. Industrial areas are particularly warm. The boxplots of residential areas and social infrastructure have a strong deviation and many outliers. They probably include more open space and vegetation than the inner city.

The natural areas have the fewest summer days. Apparently, the fresh air production and the shading of trees might have a stronger cooling effect on air temperatures than water bodies. Agricultural land has no significant cooling effect because of the low amount of high vegetation (for example trees).

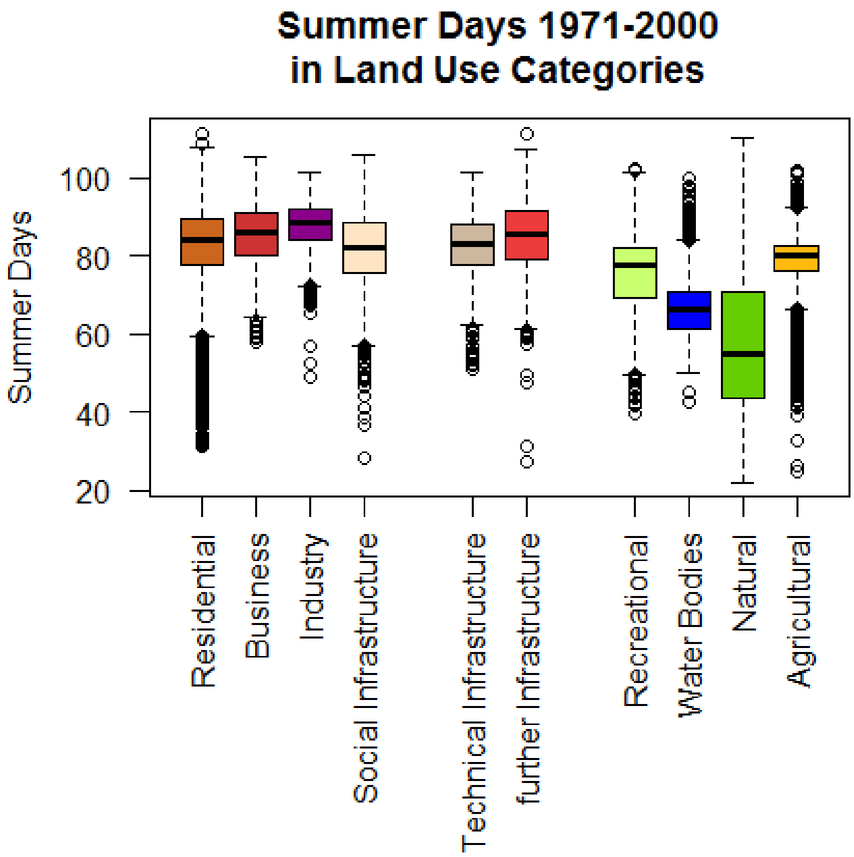



**Figure 6: Summer days in Vienna in the different land use categories[8] (source: own illustration; data: ZAMG 2013b).**

The land use data are taken from 2007/08 because no data are available for the time frame 1971-2000. Thus, Figure 6 does not include the land use changes over these years.

## 3.2 Indicators of Heat Related Vulnerability

The first step of this analysis is to show the current situation and distribution of heat related vulnerability in Vienna. Afterwards, a comparison with the possible future development will be made. Climate change is dependent on a wide range of factors and their interdependencies. Its future development can be influenced by human activities. To include different possible developments of human activities the analysis will use climate scenarios to describe the future.

This thesis uses different indicators to approximate the terms sensitivity, exposure and adaptive capacity in the context of heat stress. The individual indicators are described in the following sections.

### 3.2.1 Exposure

As mentioned above the exposure to heat depends on air temperature, humidity, wind, radiation and duration of a heat period. According to the literature, indicators like the number of summer days or tropical nights within a time period are often used to approximate these

[8] The land use category “streets” was not included because of the spatial resolution of the data of summer days (100x100m): due to the width of streets no useful information of the particular microclimate of streets can be obtained from this data. Data from 2008 is used for the land use categories, because there are no data available for the last 30 years.

factors (see e.g. Lung et al. 2013; Žuvela-Aloise et al. 2013). Summer days are the days with a maximum temperature of ≥25°C, tropical nights are defined as nights with a minimum temperature of ≥20°C (Lung et al. 2013, 524). These indicators also include the possibility of heat waves as the occurrence of more summer days in general leads to a higher probability that these days are consecutive. The threshold of summer days seems useful according to the heat threshold mentioned in section 2.3.1 Influence of Heat on Human's Health. Therefore, summer days are used as an indicator for the exposure.

### 3.2.2 Sensitivity

The literature from section 2 suggests following factors to indicate the sensitivity of the population to heat stress.

- Population: the population is a key factor as the impact on people is of interest in this study.
    - Population density indicates whether people are affected by heat or not.
    - Additionally to the general distribution of population, the distribution of age is of interest. Population aged 60 and above is considered for this indicator.
    - Due to the higher risk for women to die from heat stress, the distribution of male and female population will be included.
- Illness, medication: medication has a great influence on the body's ability to cope with heat, but there are no data available that would allow a spatially differentiated approach due to privacy protection. It will thereby not be included in the analysis.
- Financial situation: the ability to cope with heat financially is important on an individual level[9], but there is no information accessible on a high spatial resolution. Furthermore, there are no reliable models available which suggest how the financial situation will be distributed over the city in the future.
- Given the possibility of significant changes over time no economic factors are included.
- Social isolation: there are no data available which directly indicate the social isolation of the Viennese population. Vulnerability studies use different approaches to approximate this situation. They cannot be directly transferred to Vienna as regional patterns and habits influence the situation of social isolation. An additional study to collect such data would be necessary. However, this is not possible in the scope of this thesis.
- Buildings to approximate the indoor temperature: according to the ÖNORM on heat protection in buildings many specific factors for each building influence the indoor temperature like the used materials, the orientation and the structure of flats, which influences the ventilation (ÖNORM B 8110-3, n.d.). It would be possible to approach the quality of buildings by the time period of construction (with a lack of information about renovations), but for the other parameters there is no information available for the entire city. Therefore, the indoor temperature is not included in this study.

The following indicators are indirectly deduced from the theory, thus, they are pointed out and explained here: the access to health care and to compensating areas. The first is included

[9] see e.g. the study of Harlan et al. about neighbourhood microclimates in Phoenix/Arizona, which supports the hypothesis that the risk from heat is greater for marginalized groups (2006).

because medical attendance might be necessary due to heat stress. In the case of heat waves facilities might be overloaded, thus, indicators like practitioners per 1000 inhabitants are of interest in such situations. The latter indicator is used to contribute the fact that people may also suffer from heat stress in open spaces. Additionally, they might need compensating areas if the indoor temperature becomes too high.

Furthermore, the social aspects of open spaces are important to avoid potential isolation.

- Access to medical attendance: General practitioners (GP), hospitals and retirement homes are used as indicators. A combination of the distance to the next facility and the number of facilities within walking distance is used. The possibility of people walking to the next facility includes the fact that people consult a GP before an emergency situation occurs: people seek medical help when they suffer physically during heat and not only when an ambulance is already needed. Ten minutes are considered as acceptable walking time. With a mean walking speed of people aged 60 and above of approximately 1.3m/s (according to Bohannon 1997, 17), facilities in a radius of 800m are included.
  The retirement homes are only used for the density of facilities to include that people living there already gain medical attendance. But they are not relevant for people living nearby to seek medical treatment.
- Access to compensating areas: open or accessible spaces with cooling potential are of interest for this indicator.

Acclimatisation of the population to heat is not included in the analysis as no knowledge about the speed of acclimatisation exists. It can thereby not be transferred to this study.

### 3.2.3 Impact

The different indicators are normalised from 0 to 1 to enable a comparison. Fuzzy membership is used for this calculation. The fuzzy theory allows to include the fact that an object is neither fully in one state (0, e.g. sensitive) nor in the other state (1, e.g. not sensitive) but somewhere in between.[10]

In contrast to classic logic with sets where variables have discrete conditions (true or false), fuzzy logic allows vague terms with continuous transitions from one condition to another (Demant 1993, 7f). This is of special interest in a vulnerability analysis: it deals with probabilities of risks, which have a continuous transition according to different indicators.

Different functions are available for the calculation of fuzzy membership. An S-shaped function (see Figure 7: right) is often used to allow a smooth transition towards the stages true (1) and false (0). However, a linear distribution is chosen for this analysis, because no information is available about the distributions of sensitivity and exposure that vary significantly from a linear function. The assumption of a linear distribution is thereby only an approximation.

[10] The algorithm used here is from ArcGIS 10.2, FuzzyLinear (see Esri 2014, online).

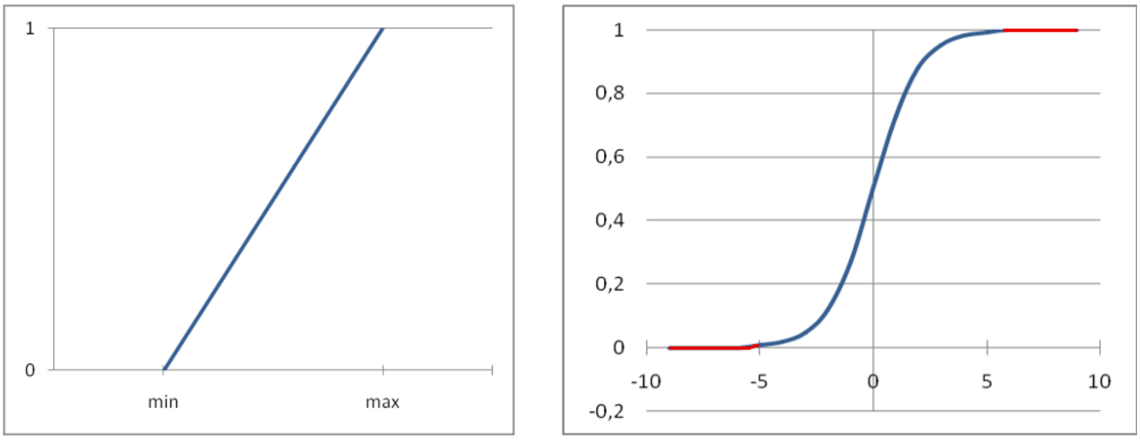



**Figure 7: Distribution functions of fuzzy membership. Left: Linear distribution of the values from 0 to 1 where 0 is the minimum value and 1 the maximum value. Right: Example of a S-shaped distribution (source: own illustration).**

Starting and end point for the fuzzy membership are defined by the 5th and the 95th percentile to avoid an excessive influence of outliers on the conversion of the values. A first analysis with minimum and maximum values used as starting and end points showed that outliers would have this influence. Differences within the rest of the values, which are important for the analysis, are reduced due to the excessive influence of these outliers. This is due to the fact that sensitivity and exposure are defined in comparison to the values in the rest of the city. Most outliers are captured with this procedure; additionally, it is possible to use the same approach for all data inputs. The importance of this procedure for the different indicator is shown in section 3.3.

The range of values of the indicators is limited from 0 to 1, although it was mentioned above that for example a negative sensitivity would be possible to contribute to the fact that changes can also be used as a potential for improvement of the situation. This analysis of sensitivity ~~to~~ and exposure of heat deals with negative effects of climate change. Thus, these indicators can be reduced to this range.

It is important to include the surrounding areas of Vienna, because the continuous settlement structure does not end at the city border. Figure 8 shows that the metropolitan area of Vienna extends particularly to the north and to the south. These communities influence each other. Dense neighbourhoods in Lower Austria might experience in part similar heat exposure as the urban neighbourhoods of Vienna.

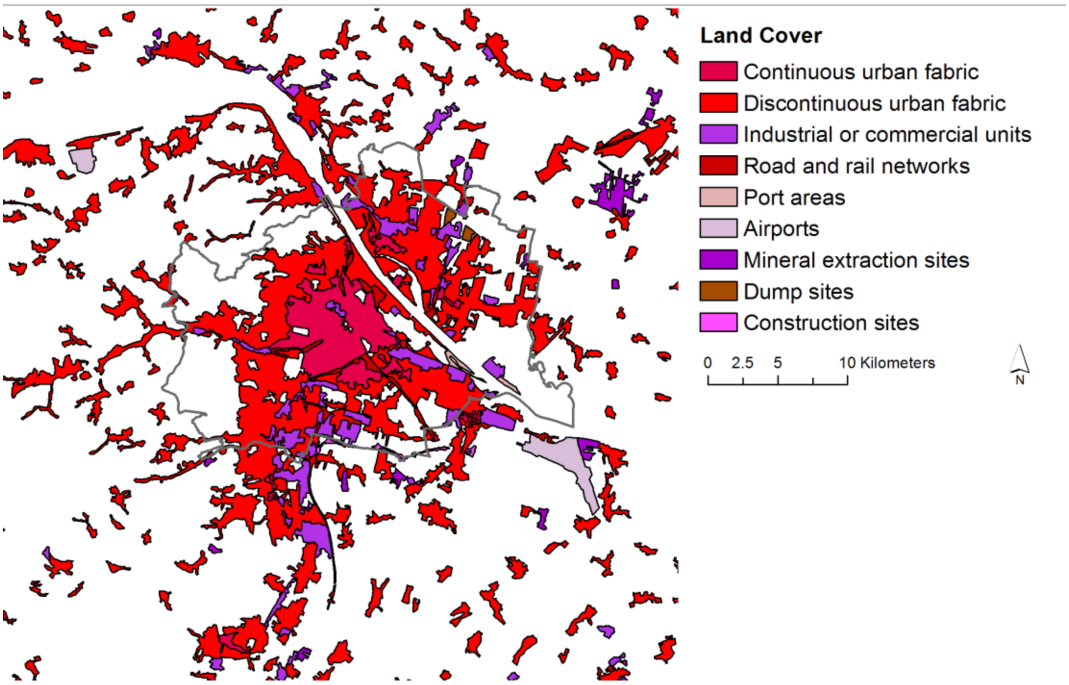



**Figure 8: Metropolitan area of Vienna: urban and industrial land cover (source: own illustration; data: Umweltbundesamt and EEA 2000).**

However, due to the different quality and spatial resolution of the available data estimations would be necessary to compare these areas in Lower Austria with Vienna. Thus, only Vienna is included in the calculations.

The population aspects of sensitivity (density, age, and sex) are merged to one population indicator. Similarly, the indicators access to medical attendance and access to compensating areas are combined. These indicators are then combined to the sensitivity ranging from 0 to 1 (see Figure 9).

The potential impact is derived from the combination of sensitivity and exposure (see Figure 9):

$$I = S * E^{11}$$

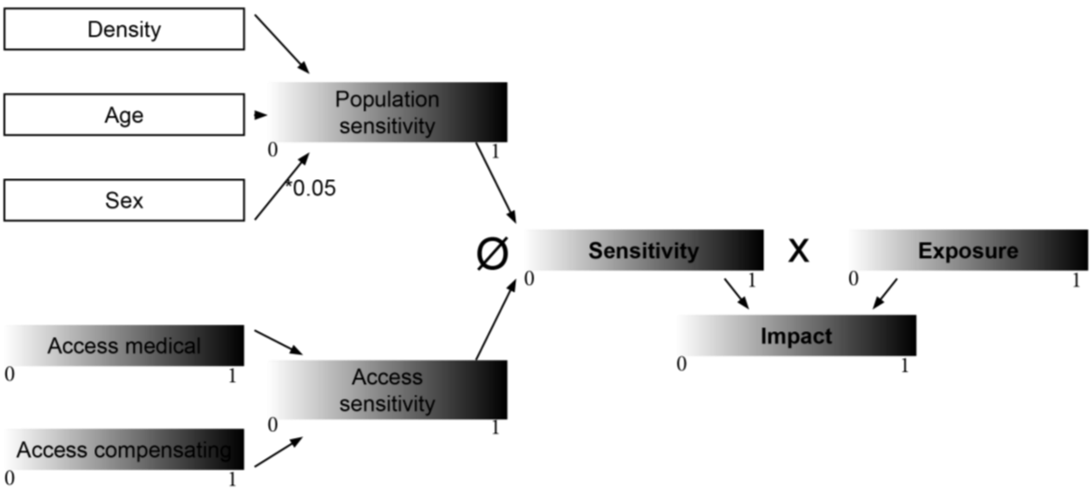



**Figure 9: Flow chart showing the combination of indicators to calculate the impact (own illustration).**

[11] I stands for the impact, S for the sensitivity and E for the exposure.

The impact is thereby a non-dimensional value ranging from 0 to 1. It would be possible to weight individual indicators of sensitivity or exposure. The knowledge about the amount of contribution of individual factors to the impact is limited. A comparison with actual incidents of heat stress in Vienna would be necessary for defining weights. The implicit weighting that is used here is only an assumption as this information is not available with a high spatial resolution.

### 3.2.4 Adaptive Capacity

As mentioned before, adaptation measures to the changing climate conditions are necessary because climate change is no longer preventable, even if there was a high degree of mitigation. The impacts of global warming can be addressed on the local level where they occur. A variety of strategies has already been developed in the past and some of them are already being implemented in some regions (Rannow et al. 2010, 160ff). However, they are still in their early stage due to uncertainties about climate change impacts, which make it difficult to put them into action (Rannow et al. 2010, 160ff). The form of adaptation strategies depends on the different effects of climate change which they try to reduce.

Thus, the adaptive capacity is an indicator of the probability to implement adaptation measures. It is thereby dependent on the specific adaptation strategies and on the scale of implementation.

In the literature, the indicators for measuring adaptive capacity vary depending on the topic of the climate change impact. Financial indicators are often used to define one aspect of the probability of implementation of adaptation, because all measures rely on financial resources. Lung et al. for example use the concept of human and technological capital in addition to the financial capital; they are measured with the GDP (gross domestic product), the Gini coefficient (to measure the equity of income), the educational attainment, health infrastructure, research and development expenditures and the level of internet use (Lung et al. 2013, 523). Thereby, they include the fact that the implementation of measures needs human activities but also that new forms of adaptation might be developed in the future. The European Commission on the other side suggests using income, educational level and emergency response amongst others as indicators for adaptive capacity in their “adaptation support tool” (European Commission 2014, online).

The probability that adaptation is implemented cannot be measured by financial indicators of the public sector for the sub-district level of a city as it is not clear for which areas the financial resources of a district will be used. Therefore, in the following chapter different adaptation strategies are discussed in order to develop indicators for the adaptive capacity. The focus is set on spatial planning measures.

#### 3.2.4.1 Adaptation Strategies

Adaptation strategies in general include all possibilities of adapting to heat stress. From the variety of strategies this study focuses on measures that are important for spatial planning. To give an overview and to illustrate their consequences and implications the different adaptation strategies are classified.

### Reducing UHI – reducing effects

The most fundamental differentiation of strategies is between measures that reduce the heat island and measures that decrease the negative effects of heat events. In the long term it is important to focus on the measures that actually reduce the UHI effect. Due to the uncertainty of rising temperatures over the next centuries, the costs of absorbing the negative effects are difficult to estimate. If, for example, a heat wave is addressed with increased use of air conditioning, the electric grid will be stressed due to the additional energy consumption; in some US and Australian cities this can lead to brownouts (Grimmond et al. 2010, 250). In this case, the whole infrastructure would need to be constructed for the rare events of heat waves. Additionally, preventing the creation of a severe UHI is also a contribution to climate change mitigation because of the reduced heat release. This can have feedback effects on the climate affecting a city by influencing the creation of heat waves.

### Individual – collective

It is also important to differentiate individual and collective measures. The individual level influences some of the indicators that were used to define the sensitivity of the population, e.g. the possibility to use air conditioning or other indoor improvements is related to the financial situation of people. There are also several possibilities in changing personal habits like wearing clothes in bright colours or consuming enough water (see e.g. recommendations of WHO 2009, 33).

The collective level includes the public sector and thereby particularly the adaptation measures provided by spatial planning. It is therefore the focus of this study. This is important as heat stress is a problem produced by society and not by individuals. Furthermore, heat is not distributed equally among a city, i.e. the population is unequally affected. Harlan et al. suggest in a study on Phoenix that marginalized groups (poor, minorities and elderly) are mainly effected by heat stress because they live in warmer neighbourhoods and due to the lower quality of the building materials (Harlan et al. 2006, 2860). These are the groups that have the least chance to cope with heat individually.

Measures trying to address individuals (air conditioned public rooms, medical facilities) might imply barriers; the research of Sampson et al. found ~~out~~ that people in the US would avoid government facilities due to their immigration status (Sampson et al. 2013, 480). This might also be the case with seeking medical attendance.

### Regional – Local – Site-specific

It is also important on what scale the measures take place. The levels can be differentiated as the regional, the local and the site-specific. The latter mainly includes technical measures like the use of cool building materials as for example materials with a high albedo (Grimmond et al. 2010, 101). The greening of buildings (for example green roofs and facades) can also be included in this level. If private objects are concerned, the realisation will depend on the ownership structure and decisions of private stakeholders.

On a larger scale the city structure and the settlement development can be influenced in a way that minimises the heating of the city. This can be enforced for example by considering ventilation directions, protecting and creating green areas and water bodies or greening streets and public spaces. These considerations mainly depend on public decisions which, however, may interfere with private interests.

On the regional level, the cooperation between neighbouring communities is important to protect areas which provide fresh and cool air. Thereby, the urban development of the city but also of the surrounding communities can be influenced. For Vienna, this level is in part covered by the Planungsgemeinschaft Ost (PGO), which is an association to coordinate Vienna, Lower Austria and Burgenland in questions concerning spatial planning. The importance of this cooperation for heat island adaptation can be seen in the "Wienerwald"-declaration of 2002. It defines targets and actions to be set for the Wienerwald. These targets include the preservation of the forest as an area of ecological and recreational importance for example by limiting the settlement development (PGO 2002, 2–3).

The protection of forests in the city region is particularly important for the provision of fresh air with consideration of the wind directions. Winds coming from north-west deliver ~~the~~ air that is produced in the Wienerwald to the densely built-up city centre. The fact that different interests are involved in such decisions due to the variety of actors will be handled in the following.

INSTITUTIONAL – FINANCIAL – TECHNICAL

The probability of measures to be implemented is dependent on their feasibility on three levels: the institutional, the financial and the technical level. Figure 10 illustrates the interrelation of these levels to enable adaptation.

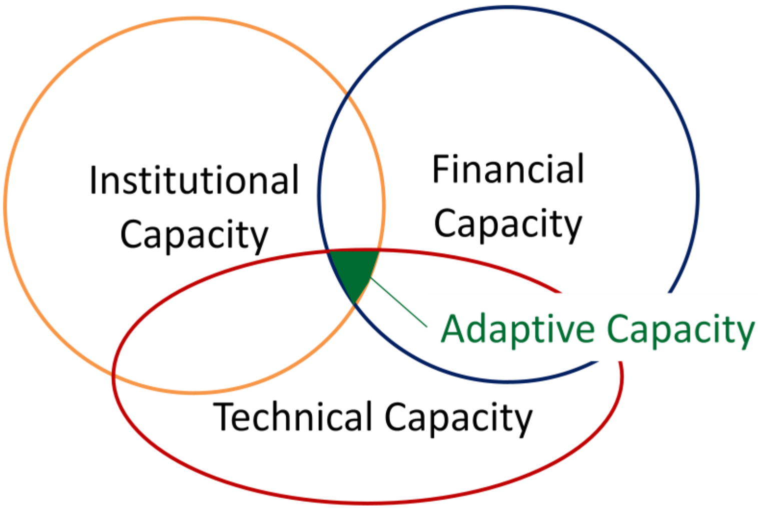



**Figure 10: Interactions of the levels of adaptive capacity (own illustration).**

The suggested concept illustrated in Figure 10 indicates that capacity is needed in all three levels to provide an adaptive capacity and in consequence to enable the implementation of adaptation.

The institutional level includes instances that enable direct measures: plans, strategies, laws, information and the networks between people. The integration of the topic "heat" in development plans, strategies or laws is fundamental in order to realise coordinated actions of adaptation. Institutions, which might influence the temperature of the city and the coping of the population by their actions, need the information and the awareness to implement measures with respect to heat stress. The network of involved actors may enforce the implementation. Since different actors bring in different interests, plans and strategies can represent compromises. Therefore, the question of who participates in these processes is crucial. Due to the fact that this question would need an additional research, it cannot be answered in the scope of this study.

The inclusion of heat in development plans can encourage the creation of new green spaces in areas with a high heat impact. In Vienna the climate change adaptation strategy is included in the Climate Protection Programme 2010-2020 (KliP II). The programme mentions that adaptation measures should be developed; however, the uncertainties about climate change and therefore the need for further research are emphasised (Magistrat der Stadt Wien 2009, 195–197). Measures are specified in the evaluation of this programme from 2013. It divides adaptation into six different fields of action: “urban planning and infrastructure”, “energy”, ”health”, “water”, “disaster control” and “green” (Austrian Energy Agency 2013, 211). It suggests the creation and preservation of green and public spaces in the field of urban planning (ibid., 212), but there is no information on how and where this should be done. It refers to studies that are developing strategies at the moment. The project “Urban Heat Islands” is developing suggestions for urban planning in this regard (ibid., 211). In the context of energy the measures are more specific. The evaluation suggests measures on buildings as for example rehabilitation of buildings to reduce energy consumption (ibid., 212). The explanations miss a connection between the different fields of action, which are actually influencing each other. Thereby, synergies and contradictions might be ignored. The adaptation strategy is still being developed and will therefore still need time for implementation. Nevertheless, clear guidelines would be needed to facilitate the implementation of adaptation.

The green and open space concept of the urban development plan is more practical. It provides the new method “local green plan”. This plan should be made in the case of a restructuring of neighbourhoods. It provides a set of 12 different open space types which should be combined to a network and thereby provide qualitative open spaces. The possible regulations within such plans do not differ from the ones in already existing plans but the local green plan tries to focus on green structures. One aspect of green spaces mentioned in this concept is the effect on the city climate (Stadt Wien/MA 18 2015, 32, 81–82).

Furthermore, the social and health system can also be included in the institutional level. It influences the adaptive capacity by determining the possibilities of people to seek help in a case of emergency.

The financial level includes the control of cash flows for coping with heat stress. It can be divided in direct investments of the public sector (e.g. construction of parks), funding for private persons so they implement adaptation (e g. through subsidising specific cooling measures on buildings) and the financial situation of the population. The first two are dependent on the budgetary situation of the state. It is difficult to forecast the financial situation for a longer time horizon due to the variety of factors of the global economy influencing it. Additionally, it is not clear if investments in adaptation will be done and where such investments could be located within a city. Therefore, it will not be included in the analysis.

The technical level includes all measures of physical intervention. The institutional and the financial levels are – but not limited to – the preconditions for the implementation of measures on a physical level. Table 1 categorises technical measures that influence the creation of UHIs according to Mahdavi et al. (2014). These measures were suggested in the context of the “Urban Heat Island” project mentioned above. Thus, they might gain in importance for urban planning in Vienna in the future.

| Category | Measure | Expected benefit |
|---|---|---|
| Buildings | Cool roofs | High solar reflectance and high thermal emissivity |
| | Green roofs | Shading (intensive green roofs) and evapotranspiration |
| | Green facades | Reducing ambient air temperature, shading properties, natural cooling, control airborne pollutants, energy efficiency |
| | Facade construction and retrofit | Reducing cooling/heating load, reducing ambient air temperature, improving building envelope quality |
| | Geometry of urban canyon (new projects) | Fresh air advection, cool air transport into the city |
| Pavements | Cool pavements | Decreasing ambient air temperature |
| | Pervious pavements | Storm water management |
| Green areas | Planting trees within the urban canyon | Shading and evapotranspiration, lower peak summer air temperatures, reducing air pollution |
| | Parks, green areas | |

**Table 1: Technical measures to access urban heat (source: Mahdavi, Kiesel, and Vuckovic 2014, 512).**

With consideration of the interdependency of mitigation (prevention of global climate change) and adaptation it is important to assess heat stress at the sources of the UHI. These are changes in the surface albedo, evapotranspiration, wind and anthropogenic heating (Taha 1997, 99–100; Grimmond et al. 2010, 251).

Air conditioning systems will not be included as an adaptation strategy, because such systems produce anthropogenic heat waste themselves. For the Phoenix metropolitan area, a region with a high amount of air conditioning use, Salamanca et al. suggest that air conditioning rises the mean 2m air temperature between 0.5 and 1°C (2014, 5963). They are thereby only the last possibility of coping with heat when other measures fail.

The implementation of technical measures depends on the different time frames in which they can be realised but also on the probability of realisation. The destruction of whole city quarters is less probable and more difficult (due to social aspects and costs) than planting trees within the existing structures. Furthermore, the integration of heat adaptation considerations in the construction of new city development areas provides particular chances that might also influence the surrounding areas.

MOBILITY

Anthropogenic heat waste can be reduced by changes in transportation patterns: reduction of motorised transportation leads to a decrease of anthropogenic heating. It is mentioned here as an individual topic because it is related to all three levels: the institutional level is crucial for public transport: for example, a focus on walking or the use of bikes can be made; the substitution of public transport is part of the financial level. On the technical level the structure of the city can be changed for example according to the concept of the compact city.

No information about the effect of transport on the UHI exists for Vienna at the moment. Therefore, transport and mobility cannot be assessed in the context of microclimate in Vienna in the scope of this thesis.

#### 3.2.4.2 SPATIAL PLANNING STRATEGIES OF ADAPTATION

Spatial planning has different possibilities of assessing heat stress. According to the attempt to reduce the UHI effect, following measures are important for spatial planning:

- Unsealing: increased evapotranspiration compared to sealed surfaces
- Green areas and water bodies: increased evapotranspiration and shading
- Ventilation: provision of fresh and cool air; mainly a long term measure as changes in the urban structure are necessary
- Mobility/transportation: reduction of motorised transportation lead to a decrease of anthropogenic heating

Below, the planning suggestions from the project "Urban Fabric Types and Microclimate Response" are presented. This project assessed the microclimate of Vienna especially in the context of heat stress. As the influence of specific measures on the city climate depends on the place they are implemented (Stiles et al. 2014, 8—2–8—11), different measures were simulated for representative areas of Vienna in that project. The following suggestions were derived from these simulations. Furthermore, they are narrowed down according to the probability of their implementation (Stiles et al. 2014).

- <u>Tree planting</u>: trees have climatic effects on a local level but also on the whole city due to shadowing (dependent on the leaves and the height of the trees), evapotranspiration and wind reduction. Groups of trees intensify the effect of each other and should thereby be preferred. Along the facades of buildings, trees can increase the shadow on both the street and the building dependent on the side of the street and the urban structure. The planting of trees is particularly important in wide streets that are more exposed to sun than narrow streets. A focus should be on junctions, because they are exposed by wind and sun. The same applies for squares. The potential for tree planting also depends on the actual use of an area that should not be disturbed by the trees. Finally, trees affect the sky view factor (amount of sky that can be seen from the ground), which has a negative influence on the nocturnal cooling (Stiles et al. 2014, 8—2–8—5).
- <u>Unsealing</u>: the thermal properties of the surface depend on its colour and material by defining its albedo, its capability of heat and water storage. Vegetation influences the climate by transpiration; water bodies influence it by evaporation. If neither of those is possible unsealed and bright materials are preferred for the surface. Unsealing has

strong effects in big court yards without trees and squares. In court yards unsealing does not interfere with the use of the areas (as it would be the case in streets) and might have strong influence on the surroundings dependent on the wind direction and building structure (Stiles et al. 2014, 8—6–8—8).

- Roof greening: roofs are in sum a large sealed area. Vegetation provides shadowing of the roofs. Leaves' surfaces do not heat due to the specific properties of leaves. Additionally, green roofs have a water retention capacity and provide habitats. The greening should cover as many roofs as possible. The climatic effect is stronger with intensive greening than with extensive greening, because it includes a thicker soil layer and more vegetation. Areas that are large and connected have a higher microclimatic effect. Furthermore, low roofs have an effect on the neighbouring buildings (Stiles et al. 2014, 8—8–8—9).
- Further suggestions: in general, it is important for climate sensitive urban planning to provide a high amount of vegetation and water expanse. Trees are preferred in contrast to smaller vegetation. Vegetation has a stronger climatic and ecologic effect when the areas are connected. Greening of facades can have a positive effect on a building's energy efficiency and on the microclimate of the surrounding areas. If the planting of trees is not possible due to the structure or the use of an area, technical and architectural measures can be used for the shadowing. Vertical water elements (e.g. fountains) provide cooling and increase the air humidity. Furthermore, seasonal aspects are important for planning decisions. In cold seasons warming caused by the sun and protection from wind are important while in summer the opposite is preferred. In this context, broadleaf trees are favourable. However, they still have a shadowing effect without leaves. Trees also slow down the wind speed. These general suggestions were not included in the simulation of the urban fabric project, but are important for planning decisions (Stiles et al. 2014, 8—9–8—10).

The probability of implementation of certain measures depends on the time frame. The suggestions by the urban fabric project are possible to be realized in the near future, whereas changes in the ventilation are mainly limited to new development areas and long term considerations.

#### 3.2.4.3 INDICATOR

The indicator for adaptive capacity is the potential of implementation of planning strategies. For the analysis of the near future the findings of the urban fabric project are used.

The output of this project are urban fabric types with similar structures of the open spaces and similar microclimate. This was made by clustering the areas of Vienna according to their climate, topography, open space and vegetation and building structure. Nine clusters were derived from this analysis. Three of them were divided again with a cluster analysis because of their inner heterogeneity. The areas are defined by quadrants of 500x500m. The size of the quadrants allows the analysis on a small scale and the connectivity of neighbouring open space types is still included in the considerations (Stiles et al. 2014, 5—1–5—9).

The urban fabric types (UFT) that were derived from this analysis are shown in Figure 11. They are described below.

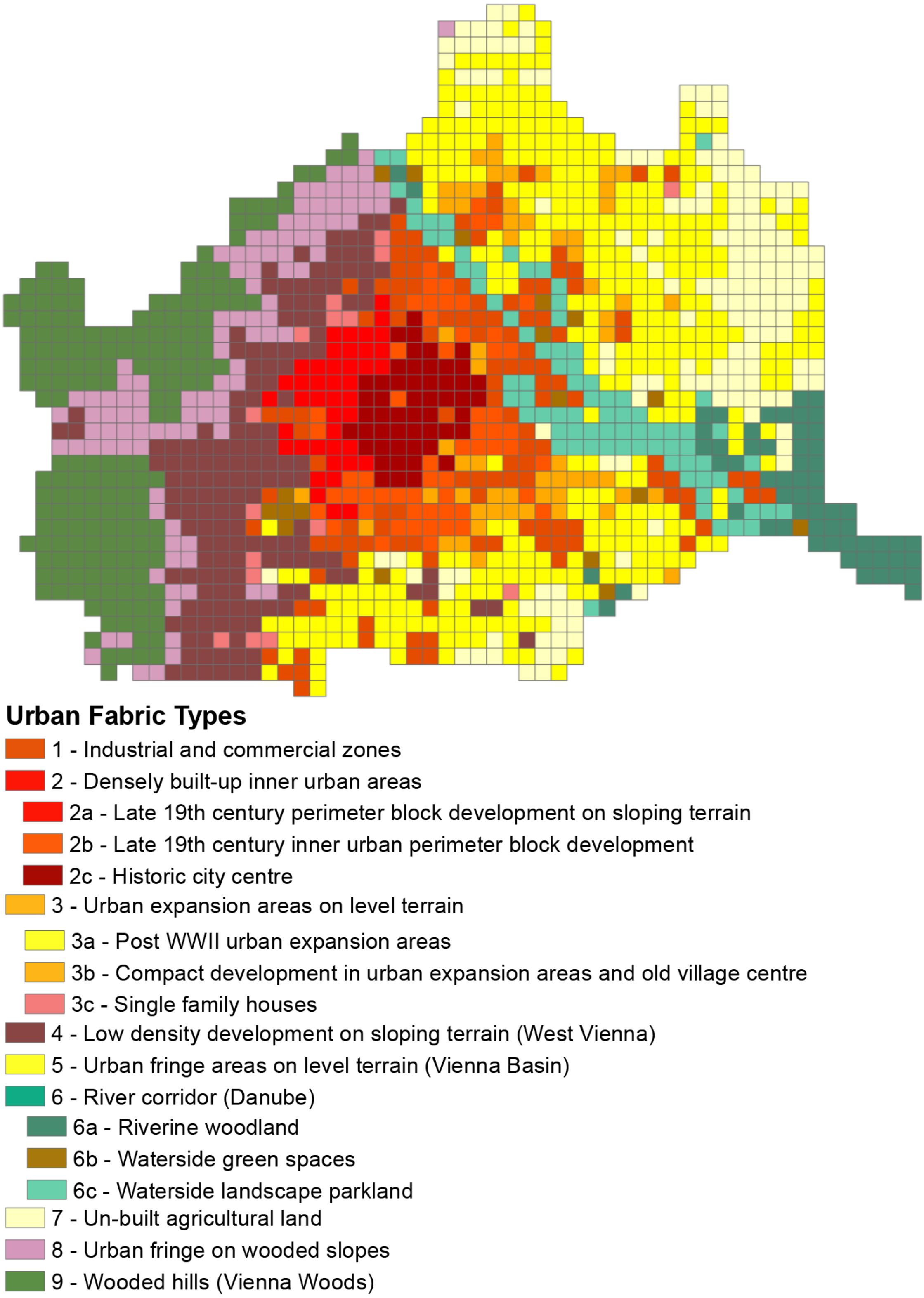



**Figure 11: Urban Fabric Types (source: Stiles et al. 2014).**

<u>1 - Industrial and commercial zones</u>: this UFT has a high amount of sealed area. However, only 21.5% of it is covered with buildings. The shadow from buildings is little due to the low-rise buildings and the wide distances between buildings. There is a high amount of grassland in comparison to other inner city UFTs. The amount of vegetation with a height of 0.5-3.5m is little. The climate is similar to the urban centre: it is warmer than in other UFTs and the

surroundings of the city and the number of hot nights (minimum temperature >20°C) is high (Stiles et al. 2014, 5—13).

2 - Densely built-up inner urban areas: this is the UFT with the highest amount of sealed area, the highest amount of built-up area and the highest mean building height in Vienna. The high amount of building volume serves as heat storage. The narrow street canyons hinder the ventilation. However, they also provide a high amount of shadow in the streets. The amount of green area is little, whereas the number of trees >3.5m, which provide shadows, is high. The urban heat island effect is the highest in this UFT (Stiles et al. 2014, 5—14).

> 2a - Late 19th century perimeter block development on sloping terrain (West Vienna): this type is in the West of the UFT 2. The slope is distinctive. Small trees are the most common vegetation and the amount of shadow from vegetation is low. The number of streets that are oriented to the south is high. (Stiles et al. 2014, 5—15)
>
> 2b - Late 19th century inner urban perimeter block development (Inner urban Vienna; Floridsdorf): this type has the lowest amount of sealed area and the highest amount of green areas of UFT 2 (Stiles et al. 2014, 5—16).
>
> 2c - Historic city centre: the amount of sealed areas in this type is the highest in UFT 2. The high number of old buildings (some even from medieval times) serves as heat storage. The amount of green areas is low, but there also exist some big parks and a high number of trees>15m. Due to the Danube canal there is a high amount of water expanse (Stiles et al. 2014, 5–17).

3 - Urban expansion areas on level terrain: this type has a heterogeneous building structure and a high amount of grassland and agricultural area (Stiles et al. 2014, 5–18).

> 3a - Post WWII urban expansion areas (South/South East Vienna): this type is mainly situated in the East and South of Vienna. It has a mixed structure with industry, single family houses and multi-storey residential buildings. There is a high amount of agricultural land and thereby high amount of vegetation <0.5m (Stiles et al. 2014, 5–19).
>
> 3b - Compact development in urban expansion areas and old village centres (North and East of Vienna): this is the type with the highest building density within the UFT 3 and is thereby also the warmest of these three UFTs. Grassland is dominating the green areas (Stiles et al. 2014, 5–20).
>
> 3c - Single family houses (West Vienna): it is characterised by a slope and a high amount of vegetation area, which also includes high trees. The building structure is dominated by single family houses. The amount of precipitation is significantly higher than in the other two types of UFT 3. This type also has fewer hot days and nights (Stiles et al. 2014, 5–21).

4 - Low density development on sloping terrain (West Vienna): this type is characterised by the increasing slope from east to west. The building structure is dominated by single family houses with a high amount of green area (Stiles et al. 2014, 5–22).

5 - Urban fringe areas on level terrain (Vienna Basin): this type is characterised by its high amount of agricultural land and recreational areas. It has a higher amount of built-up areas than UFT 7, which is dominated by agricultural land. The building structure is dominated by single family houses. It has a high number of summer days and hot nights. The amount of precipitation is low (Stiles et al. 2014, 5–23).

6 - River corridor (Danube): it includes the Danube River with the Danube Island, parts of the Old Danube and the national park "Donauauen". The vegetation is dominated by small trees and bushes. This UFT is characterised by its high amount of water expanse (20%) and a low number of buildings (Stiles et al. 2014, 5–24).

6a - Riverine woodland (National Park 'Lobau'): due to the national park, which covers this type, the amount of built-up area is low (Stiles et al. 2014, 5–25).

6b - Waterside green spaces (east of the Danube): this type has a higher amount of sealed areas than the rest of UFT 6 (Stiles et al. 2014, 5–26).

6c - Waterside landscape parkland (Danube banks and Prater): this type has a higher amount of water expanse. The vegetation is dominated by small trees and grass land. The number of buildings within the sealed areas is low (Stiles et al. 2014, 5–27).

7 - Un-built agricultural land: this type is dominated by agricultural landscape. It has a low amount of built-up areas and a high amount of vegetation <0,5m. The number of trees per m² is the lowest in the whole city. Additionally, this is the driest UFT. This UFT includes the city development area "Flugfeld Aspern" (Stiles et al. 2014, 5–28).

8 - Urban fringe on wooded slopes: this type is the transition area between the densely built-up urban areas in the West of Vienna and the Wienerwald. The building structure is characterised by scattered single family houses. This type has a high amount of green areas. It has a higher precipitation rate than the previous UFTs (Stiles et al. 2014, 5–29).

9 - Wooded hills (Vienna Woods): it is characterised by the Wienerwald and its slope and has the highest number of trees >3.5m. The local climate has regional importance for the production of fresh air due to the forest and the topographic properties (Stiles et al. 2014, 5–30).

Simulations about the measures to influence the microclimate were made for the urban fabric types 1, 2a, 2b, 2c, 3a and 3b. The microclimate model ENVI-met[12] was used to simulate the short- and long-wave radiation of the sun, the reflection and shadowing of buildings, ground and vegetation, the transpiration, evaporation and heat flow from vegetation (including e.g. the amount of photosynthesis), the surface temperature, the water- and thermal flows in the ground and the Predicted Mean Vote (PMV – an index for thermal comfort) for representative quadrants of the urban fabric types (Stiles et al. 2014, 3–3).

The results are potential impacts of different measures in the particular urban fabric types. They are used as indicator for the adaptive capacity. Additionally, the particular adaptive capacity of new city development areas will be considered in this analysis.

### 3.2.5 Vulnerability

The negative connection between vulnerability and adaptive capacity is expressed with

$$V = S * E - AC$$

S stands for the sensitivity, E for the exposure, $S * E$ for the impact and AC for the adaptive capacity. Thus, the vulnerability decreases with an increase of adaptive capacity.

[12] ENVI-met is a three-dimensional microclimate model. It can simulate the urban microclimate with a resolution down to 0.5 m (see ENVI-MET 2014, online).

## 3.3 Scenarios

Heat stress is assessed in three stages: a reference (or baseline) scenario to show the current situation and two future scenarios to show the potential risk due to climate change. The year 2000 is used for the baseline scenario. Climate data is always taken as mean values from a longer time frame to allow a generalisation and comparison between the scenarios, because the variability between single years is based on many factors that are not necessarily of interest for this study. The near future scenario is for 2035. The remote scenario is only made to approximate the year 2100; the data is not directly comparable to the baseline scenario as some data is vague and does not allow a high spatial resolution. The remote future depends on a variety of coincidences. Therefore, no accurate statements can be provided. The possibility to create remote future scenarios always depends on the topic. Long-term population forecasts for example are not accurate on small scale (Lebhart, Marik-Lebeck, and Klotz 2007, 34).

### 3.3.1 Baseline Scenario

The baseline scenario shows the situation at the beginning of the 21st century. Following data is used to build the indicators that were defined above.

#### Exposure

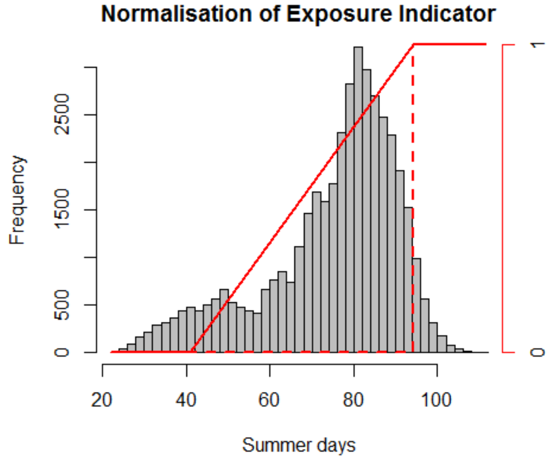
The data for the average number of summer days per year is provided by the ZAMG. They modelled the summer days on a spatial resolution of 100x100m for the whole area of Vienna for the years 1971-2000 (see Figure 5). Observational climatologic data (mean daily temperature, relative humidity and wind speed), land use patterns from the Department for Urban Development and Planning from the City of Vienna (MA18) and topography data from the Austrian Federal Office of Metrology and Surveying (BEV) were used to derive the reference model. The model is based on the dynamical urban climate model MUKLIMO_3 (“Mikroskaliges Urbanes KLIma-MOdell” – Microscale Urban Climate Model) of the German Meteorological Service (DWD) (Žuvela-Aloise et al. 2013, 4, 21).

Anthropogenic heat waste is not included in this model. There is not yet enough information on the particular influence of anthropogenic heat waste on the urban climate in Vienna.

This data of summer days from the ZAMG approximates exposure of heat on the highest resolution available for the whole city of Vienna at the moment.

Figure 12 shows the distribution of the number of summer days within the city of Vienna. Outliers are found as areas with a low number of summer days per year, which are located mainly in the Wienerwald. The right chart shows the normalisation of the values (red continuous line) from 0 to 1 from the 5th to the 95th percentile[13]. Thus, the outliers do not influence this conversion. The histogram shows the number of cases which are converted to the values 0 to 1.

[13] The dashed line shows the 95th percentile.



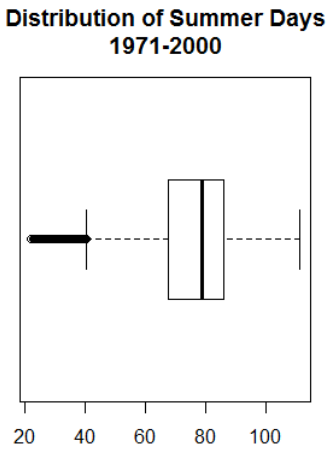




**Figure 12: Distribution and deviation of summer days. Left: Histogram and the normalisation of the exposure indicator. Right: Boxplot of summer days (source: own illustration, data: ZAMG 2013).**

### Sensitivity

Following data is used to indicate the sensitivity of the population towards heat stress in the baseline scenario:

- Population density: The data used for the population density is from the census of 2001 with a spatial resolution of the administrative level of "Zählsprengel" (STATISTIK AUSTRIA 2001). A higher resolution was not available for the whole city of Vienna.
- Age distribution: The same data as above is used for this indicator, but only the population older than 60 years. As the age is available in 5 year steps, the population is weighted (5 years correspond to a 10% higher sensitivity to heat stress) to account for the fact that the sensitivity increases with age.
- Distribution of female population: the same data as above for the population is weighted by the sex with a 5% higher risk for women[14].

Figure 13 shows the procedure of recalculation to the scale of 0 to 1 for the population indicator. The outliers can in part be explained by the definition of the spatial unit of the population data: some Zählsprengel lack open space and streets due to the definition of their boundary; however, they do not necessarily have a higher distance to the open space than their neighbouring Zählsprengel.

[14] This assumption of percentage is according to Hutter et al. 2010, 225; however, it only approximates their analysis.

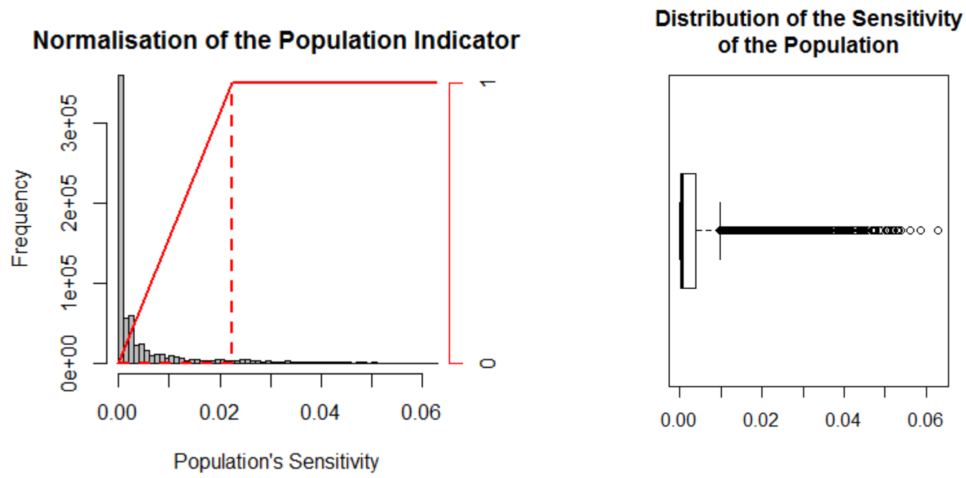



**Figure 13: Distribution and deviation of the population sensitivity. Left: Histogram and normalisation of the indicator. Right: Boxplot of the values (source: own illustration).**

- <u>Access to medical attendance</u>: The GPs and retirement homes are available from Herold-data (Herold 2014). The hospitals are taken from the city of Vienna open data portal (Stadt Wien 2014a). No differentiation between GPs is possible in the scope of this thesis due to the data accessibility and the complexity of such a differentiation. However, it would be useful to include information about the quality of the facilities as for example the opening hours, the accessibility with wheelchairs and whether it is a private or a public facility. The same applies for the hospitals. It would be useful to include information as for example the number of beds; however, this is not possible in the scope of this thesis. All hospitals are included in the analysis without any differentiation.

  As this information is based on distance, they are calculated as raster data to approximate the continuously changing pattern.

  The data for this indicator is also available for areas that are located across the city border. It is therefore included in a radius of 5000m around Vienna. The calculation of distance is based on a cost surface to include the distance dependent on the street network. The cost surface thereby describes the difficulty of traversing space dependent on the land use. It is for example impossible to traverse a building but easy to traverse streets. Additionally, green and open spaces were also weighted as easy to traverse. The land use is derived from the actual land use map of Vienna of 2007/08 (Stadt Wien 2012a). The street network is taken from OpenStreetMap, because it provides foot paths which are not included in the open data street graph from the City of Vienna. These paths are needed to include a realistic analysis for the area of the national park Donauauen (Lobau), which does not have any streets for motorised traffic.

  Figure 14 shows the normalisation and distribution of this part of the indicator. The outliers represent the areas in the national park Lobau due to its distance to the next settlement structures. Additionally, rough terrain like water expanse has high values in this indicator.

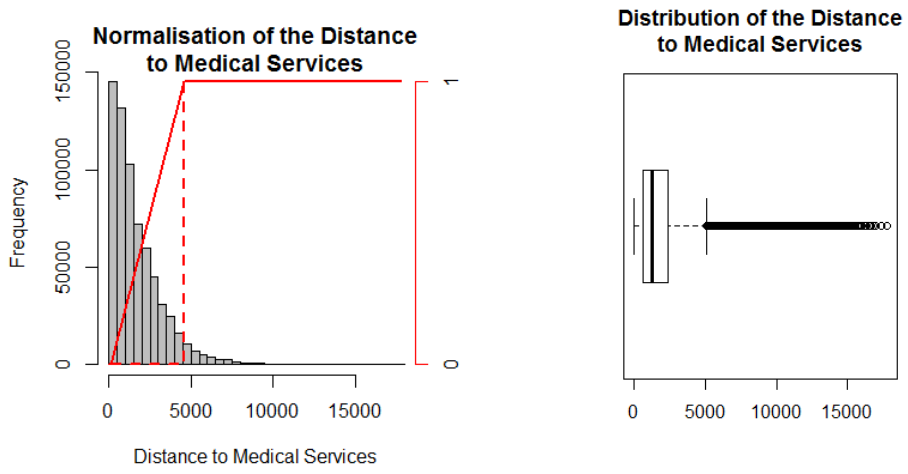



**Figure 14: Distribution and deviation of the distance to medical services. Left: Histogram and normalisation of the indicator. Right: Boxplot of the values (source: own illustration).**

The density of medical services is realised with Kernel Density[15]. This function provides a density surface dependent on the number of services and their distance to each place (Schuurman, Berube, and Crooks 2010, 33–34). The radius used as sphere of influence for each point of service is 800m as mentioned above.

Figure 15 shows the distribution and deviation of the density of medical services. The outliers are areas of a high density of medical services. These might be hospitals with an accumulation of medical facilities in their surroundings.

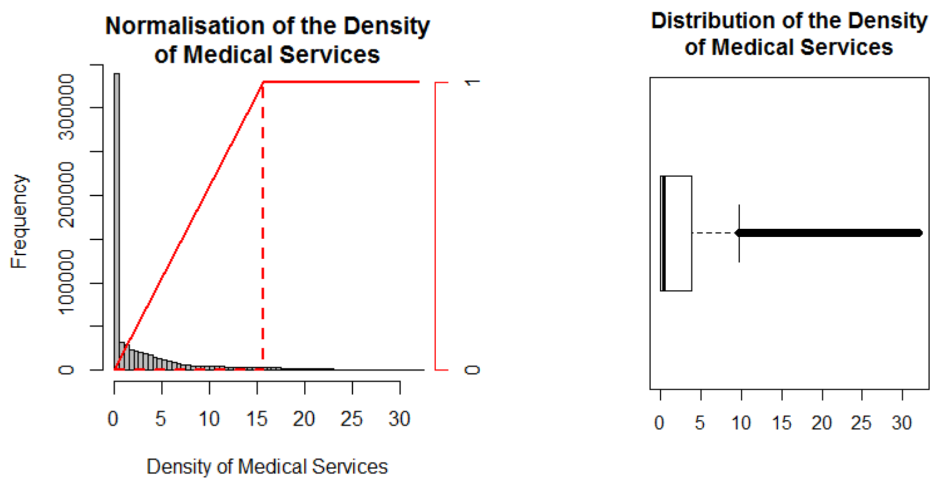



**Figure 15: Distribution and deviation of the density of medical services. Left: Histogram and normalisation of the indicator. Right: Boxplot of the values (source: own illustration).**

- Access to compensating areas: The actual land use map of Vienna from 2001 (Stadt Wien 2012b) and the tree cadastre (Stadt Wien 2014b)[16] are used to approximate compensating areas. Forests, water bodies, cemeteries, open air baths and parks are used from the land use map as areas with cooling potential. Additionally, grass land is used weighted according to the amount of area shaded by trees. The shaded area is approximated by the area of the tree tops. Grass land without any trees has an indicator

[15] The calculation is based on the ArcGIS function “Kernel Density” in the Spatial Analyst module.
[16] This data is from nowadays because no sufficient information of trees is available from 2001.

value of 0 similar to sealed areas. A similar approach as for the density of medical services from above is used to indicate the access to compensation areas. Therefore, all raster cells (25x25m) are converted to points. The points each represent an area of 625m². Thereby, the information of distance within this area is lost. From these points a Kernel Density (within 800m) for the whole city is calculated to approximate the amount of compensation area that can be reached.

Figure 16 shows the histogram and boxplot of the values of this indicator. It has a low number of outliers compared to the other indicators.

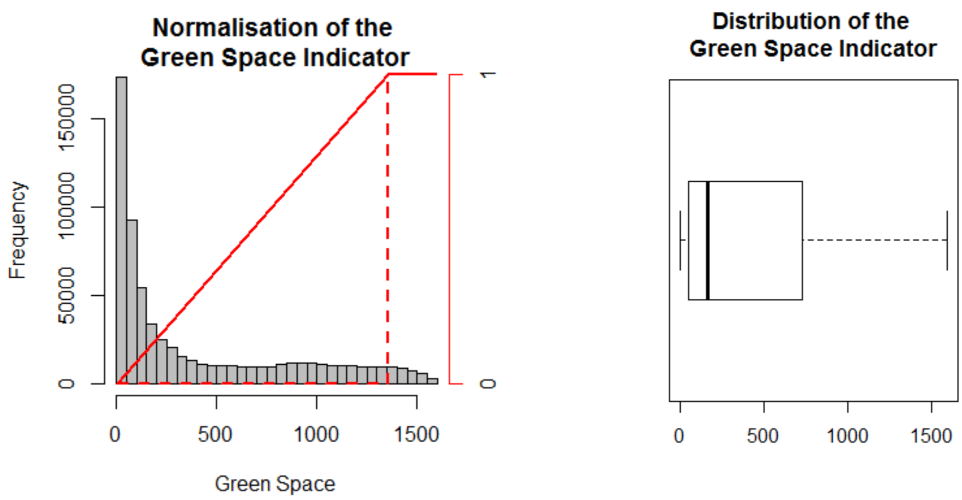



**Figure 16: Distribution and deviation of the access to compensation areas. Left: Histogram and normalisation of the indicator. Right: Boxplot of the values (source: own illustration).**

The assumption of a linear development of the sensitivity in the supply indicators of green space and medical services is only a vague estimation. At some point, a saturation of demand most probably takes place. A logarithmic function, which approximates the extreme value, may describe this development more accurately. However, more information about the value to approximate would be necessary.

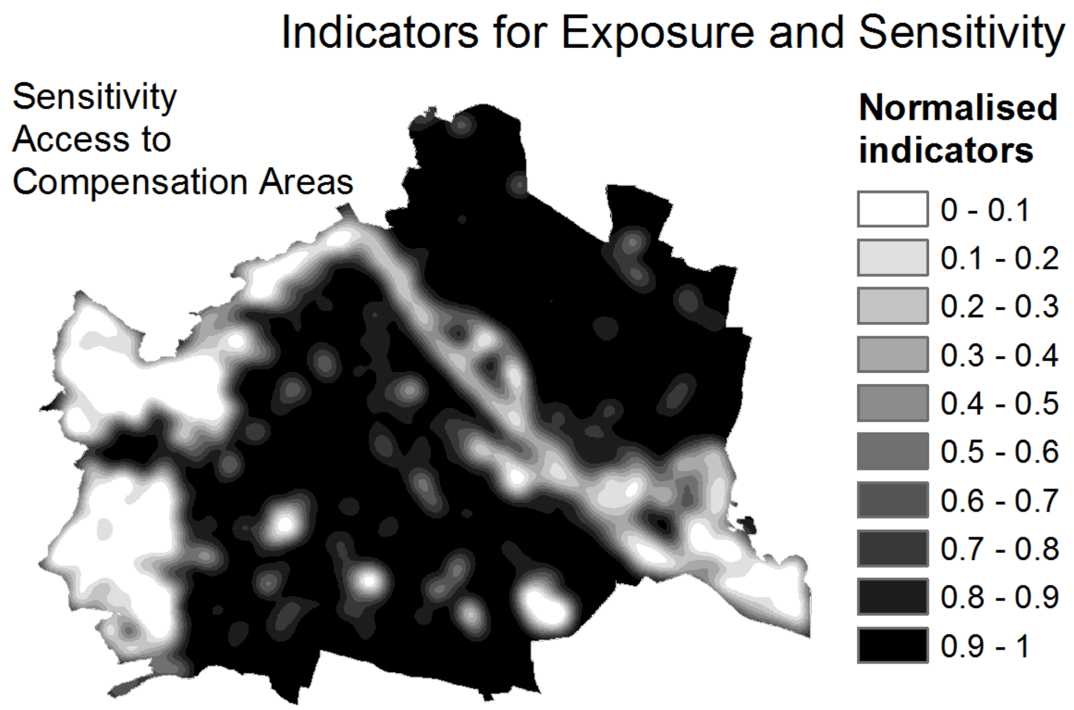
The indicators used for exposure and sensitivity in the baseline scenario are summarized in Table 2. Additional data, which is used in the following, are the district borders of Vienna (Stadt Wien 2011b). They are not used for the analysis but for visualization.

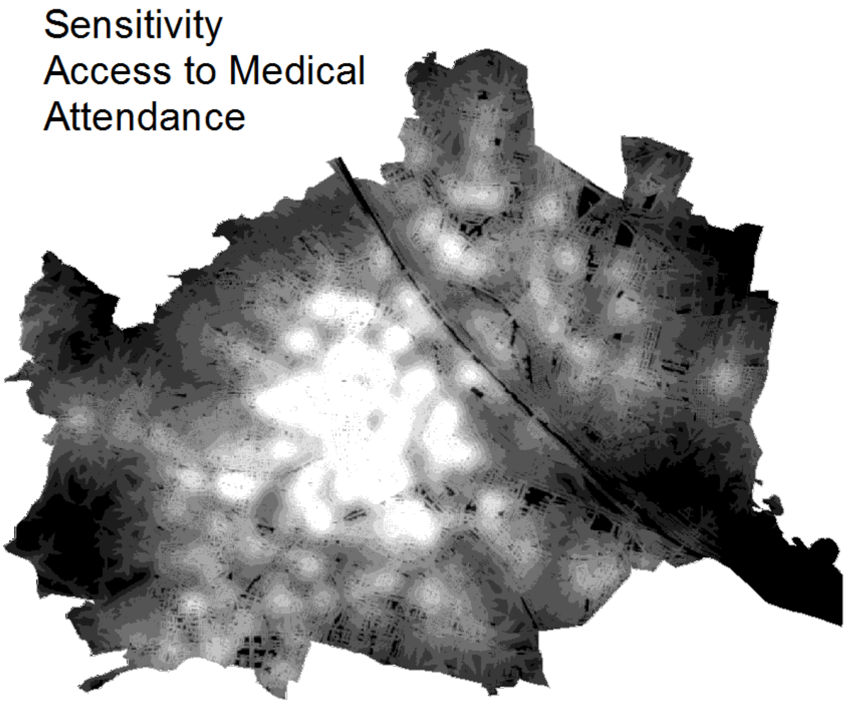
| Indicator | Data quality | Source |
|---|---|---|
| Exposure | | |
| Summer days | Raster of 100x100m, modelled data for the time frame of 1971-2000 | ZAMG 2013 |
| Sensitivity | | |
| Population Density | Spatial reference: Zählsprengel | STATISTIK AUSTRIA 2001 |
| Age | Spatial reference: Zählsprengel; age in steps of 5 years | STATISTIK AUSTRIA 2001 |
| Sex | Spatial reference: Zählsprengel | STATISTIK AUSTRIA 2001 |
| Access to medical | GPs: point data | Herold 2014 |

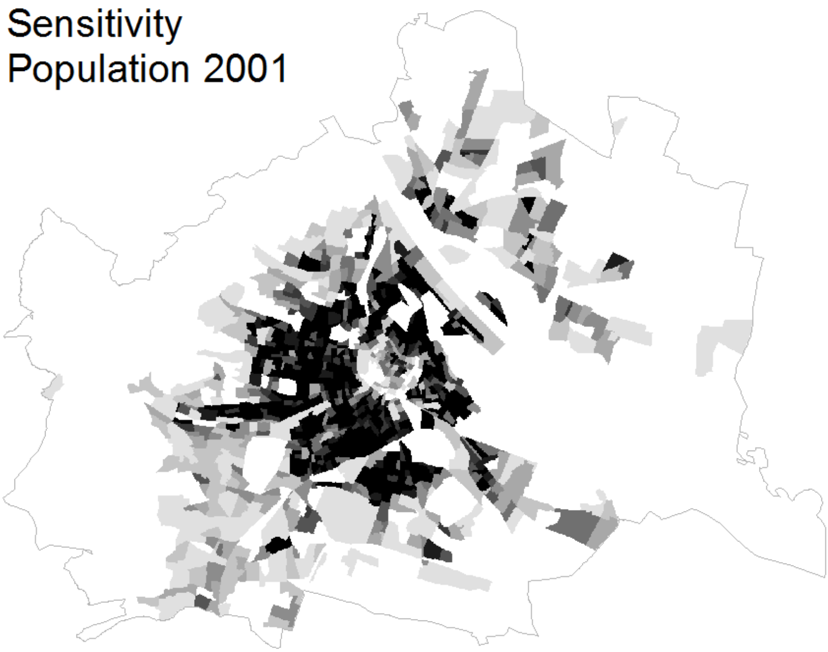
| | | |
|---|---|---|
| attendance | Hospitals and retirement homes: point data<br>Street network: OpenStreetMap | Open Government Data Vienna 2014<br>Geofabrik 2014 |
| Access to compensation areas | Actual land use map: based on the building blocks, subdivided dependent on specific situation of use<br>Trees: approx. 154 000 trees, point data | Open Government Data Vienna 2001<br>Open Government Data Vienna 2014 |

**Table 2: Indicators for exposure and sensitivity (source: own illustration).**

Figure 17 shows the normalised indicators in Vienna. The access to compensating areas and the number of summer days have some patterns in common, but it can also be seen that the details vary due to the fact that the green areas and water bodies are only some aspects among others that influence the city climate. The population indicator has a similar pattern as the access to medical attendance but in an inverted form. This allows the assumption that most medical facilities are close to the densely populated areas.




Sensitivity
Access to Medical
Attendance


Sensitivity
Population 2001

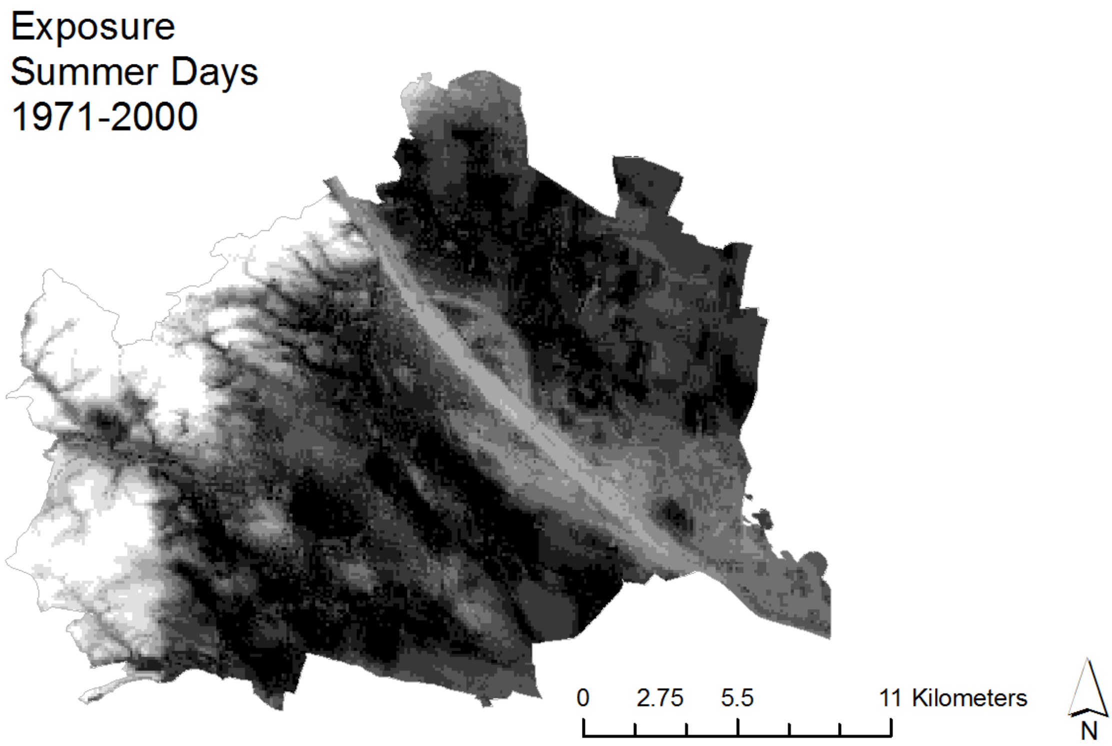



**Figure 17: Indicators for sensitivity and exposure normalised to the range of 0 to 1. Dark areas are most sensitive and exposed, respectively (source: own illustration).**

The population indicator was calculated one time including the indicator for sex and one time without it. No difference between the results could be measured. The distribution of sensitivity doesn't change whether a special sensitivity of the female population is included or not.

### 3.3.2 Future Scenarios

Scenarios are needed for the different indicators to analyse the changes that will probably take place. Anyway, not all indicators allow scenarios. For the indicator of green and social infrastructure the status quo will be used as no scenarios were available and it is not possible to build them in the frame of this thesis. The current situation is thereby only the best possible approximation. The urban development is included in the adaptive capacity. However, no detailed models are available, but only assumptions of possible development.

#### Climate

As mentioned before, the climate is already affected and will most probably be even more affected by human activities and is thereby changing significantly. The assessable development of natural phenomena and the probable anthropogenic influence can be used to model these changes. Nevertheless, incalculable events which have a great impact on the climate can take place, but for handling the consequences of climate change it is useful to deal with the most probable scenarios.

The IPCC evolved different scenarios for the climate of the 21st century. They simulate diverse developments of the human society because these developments determine the anthropogenic influence on the climate due to different concentration of the diverse greenhouse gases in the atmosphere (IPCC 2001c, 62). In consequence, with the knowledge of the impacts according to different states of society political decisions to influence these developments can be made.

In Table 3 some of the most important IPCC-SRES (special report on emission scenarios) scenarios to analyse the climate of the 21st century are described (IPCC 2001c, 63). They are also used in this study.

| | |
|---|---|
| A1 | "The **A1** storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (**A1B**) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies)." (IPCC 2001c, 63)<br>From these three sub-scenarios this study uses only the A1B scenario. |
| A2 | "The **A2** storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines." (ibid) |
| B1 | "The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives." (ibid) |

**Table 3: Scenarios of the human society for the 21st century (source: IPCC 2001:63).**

The projected anthropogenic emissions of greenhouse gases by the end of the century (2100) are highest in the A2 scenario and lowest in B1 (IPCC 2001c, 64). A1B is in the middle of these two scenarios for CO2, for N2O and CH2 it is much lower than A2 and for SO2 it is nearly as low as B1 (ibid). These emissions and therefore different atmospheric concentrations lead to different global temperatures in 2100. A1B suggests changes of nearly 3°C in comparison to 2000 while A2 suggests nearly 4°C and B1 only 2C° changes in global temperature (IPCC 2001c, 70). It has to be mentioned that these figures are calculated with a potential deviation of 1 to 2°C (ibid) and that there are great differences in the amount of warming dependent on the region (IPCC 2001c, 68).

Although these scenarios include a wide range of potential situations of the world in the course of the century, they cannot be a complete list of all possible future worlds but only of the most probable ones. Scenarios do not provide statements that come necessarily true; some developments are not easy to predict or were not predicted during the elaboration of the scenarios and therefore were not included in these scenarios. For instance, the world economic development of the last years does not fit the long-term trends of the scenarios (for the economic trends of the IPCC scenarios, see Arnell et al. 2004, 9) due to the world economic crises. The GDP per capita is also suggested to rise in all scenarios but with different speed (Arnell et al. 2004, 9). A scenario of negative economic development is not included, not even for some regions for example due to war, because such events are difficult to forecast. There is also criticism on the scenarios. For example, Arnell et al. criticise that the SRES land cover trends were inconsistent with current actual trends as for instance no scenario includes sustained deforestation (Arnell et al. 2004, 18).

To use these global scenarios on local decisions, the ZAMG used different scenarios for calculating the average number of summer days per year in Vienna for the middle and the end of the 21st century (see Žuvela-Aloise et al. 2013). Therefore they used the microclimate model MUKLIMO_3 (from DWD, see above) to simulate the influence on the city based on regional climate models (ibid, 8-9, 22). They provide the input data of potential climate changes (ibid, 8-9, 22). The data for this study is based on the scenarios A1B, A2 and B1. They are calculated with the regional climate model REMO (REgional MOdel) (ibid, 22), which is made by the Federal Environmental Agency (Umweltbundesamt) of Germany (UBA). REMO has a spatial resolution of 0.088°, which is approximately 10km (Jacob et al. 2008, 24). It is based on the global climate model ECHAM5/MPI-OM[17] from the Max-Planck Institute of Meteorology, which has a spatial resolution of 0.44° – approximately 50km (ibid.). ECHAM5/MPI-OM assumes changes in the atmospheric concentration of $CO_2$, $CH_4$, $N_2O$, $O_3$, the most important chlorinated fluorinated hydrocarbons (CFCs) and $SO_4$ on the basis of the different scenarios (ibid, 20).

It is necessary to scale down the global scenarios to the regional level because global warming does not implicitly lead to local warming everywhere. Some regions of the world might even experience cooling due to the global climate change. For example, a cooling could be measured in few areas in Europe in the last decades while the majority of Europe experienced a warming (EEA et al. 2008, 43).

REMO calculates the regional climate changes in consideration of global information and regional circumstances (Jacob et al. 2008, 18). The global model ECHAM5/MPI-OM is able to reproduce long-term climate trends of the past. The year-by-year temperature changes vary mainly due to natural influences and can therefore not be calculated with such a model (see ibid, 19).

The data for this study of the future climate in the City of Vienna is provided in two time frames: the mid of the century (2021-2050) and the end of the century (2071-2100). The data

[17] The name comes from a combination of "European Centre for Medium-Range Weather Forecasts", Hamburg and Max-Planck Institute of Meteorology. Additionally, "5" shows the generation of the model (Max-Planck-Institut für Meteorologie 2014, online).

shows the average number of summer days per year similar to the indicator of exposure in the baseline scenario and will be used in the same way for the future scenario.

The absolute changes for the Vienna region are shown in Figure 18 for the climate scenario A1B. It shows that the intense changes with more summer days per year will take place towards the end of the century. The median number of summer days changes in this scenario from 77.5 in the baseline to 88.6 for the timeframe 2021-2050 to 124.4 for 2071-2100. This indicates that changes in the next decades will be relatively low compared to the expectations for the end of the century. The deviations are relatively constant with the exception of the number of outliers in the third time frame. This indicates that the climate change is less severe in the forest areas and thereby some forested areas stay relatively cool for a longer time.

The Vienna region is thereby defined by the project region of the ZAMG for the analysis of summer days (see Figure 5). It is based on a raster which is a square around the city of Vienna. Thus, some areas outside of Vienna are included in the boxplots of Figure 18. The area outside of Vienna is in great part covered with forest. Thereby, the number of cases with few summer days is higher in this diagram as it would be if only Vienna was included. This can for example be seen by the outliers on the bottom which represent the area of the Wienerwald which is in parts located in Lower Austria.

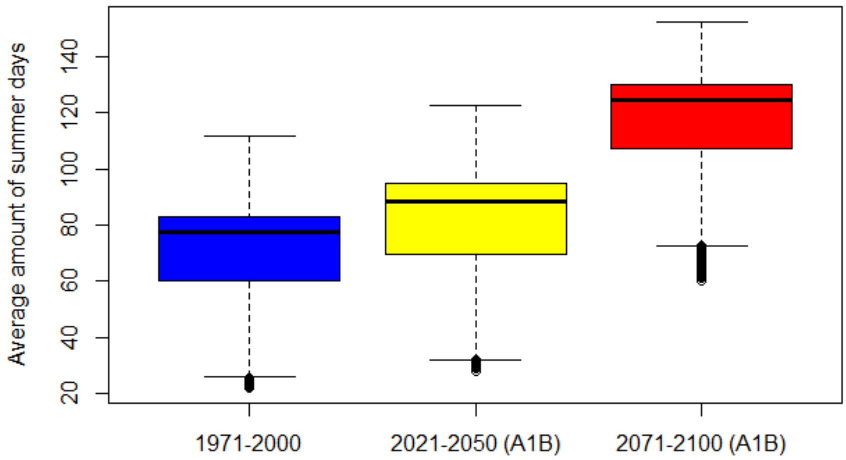



**Figure 18: Boxplots of the average number of summer days per year in the Vienna region for the time frames 1971-2000, 2021-2050 and 2071-2100. The two later ones are based on the global IPCC climate scenario A1B. (source: own illustration; data: ZAMG 2013b).**

The changes vary dependent on the respective climate scenario as can be seen in Figure 19. This figure shows data for the same Vienna region as above. It can be seen that the scenario A1B has the strongest impact of heat exposure in Vienna. Especially in scenario B1 less summer days are expected for the end of the century compared to the other scenarios. B1 is also globally the scenario with the least increase of temperature, whereas on the global scale A2 is expected to have a higher increase of temperature than A1B. Some local trends might be intensified in the A1B scenario. The differences between A1B and A2 are mainly during the timeframe 2021-2050. Thus, the stronger heat exposure in A1B might be influenced by the population scenario. A1B suggests a strong growth of the world population until the middle of the century and thereby influences the local temperature.

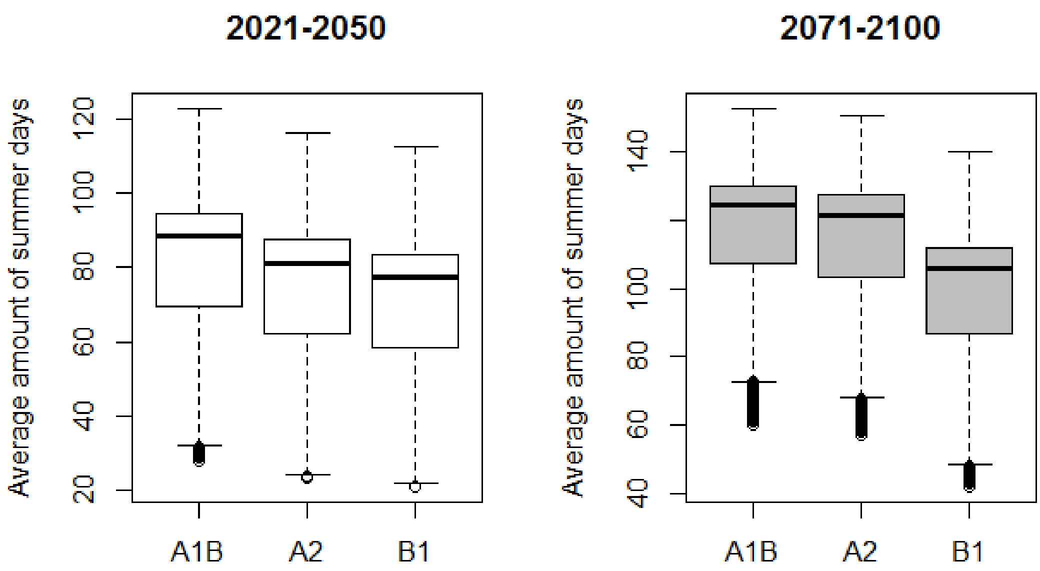



**Figure 19: Boxplot of average number of summer days per year in the Vienna region for the time frame of 2021-2050 (left) and 2071-2100 (right) in the three global climate scenarios A1B, A2 and B1. Note the different scales of the left and right panel (source: own illustration; data: ZAMG 2013b).**

The data of future summer days does not include possible city development and therefore changes in the urban morphology. The urban structure influences the microclimate and thereby the number of summer days (see above). Thus, this data is only a simplification and approximation of the potential future heat load of Vienna. The ZAMG calculated the number of summer days with the scenario of a growth of Vienna in the rural areas and an increase in density in the existing built-up areas with low density (Žuvela-Aloise et al. 2013, 17). The potential changes in heat load due to such city development are shown in Figure 20. The changes in summer days are not limited to the new built-up areas but influence a great region around them mainly due to the wind coming from north-west and south-east. This indicates the importance of preserving green areas in these neighbourhoods and preventing further urban sprawl.

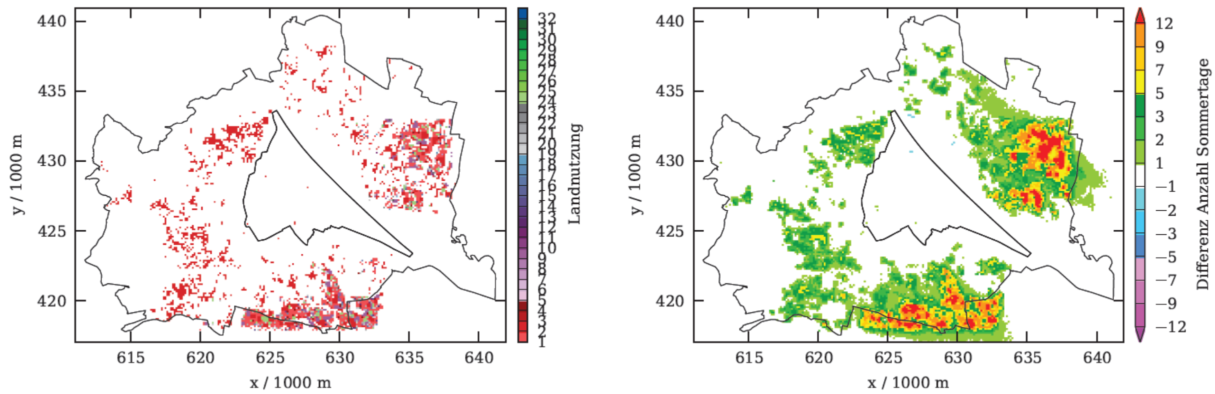



**Figure 20: Simulation of summer days with increased urbanisation. Left: the changed land use patterns. Right: the changes in summer days (source: Zuvela-Aliose et al. 2013).**

## Demography

The world population is constantly changing dependent on a variety of factors for example the social and economic situation and development in different regions. At the moment the world population is growing. In the last decades this growth is reducing speed (see Figure 21). This trend is expected to continue in the 21st century according to the scenarios from the United Nations Department of Economic and Social Affairs (2013) towards a nearly stagnating world population in the end of the century (Figure 21).

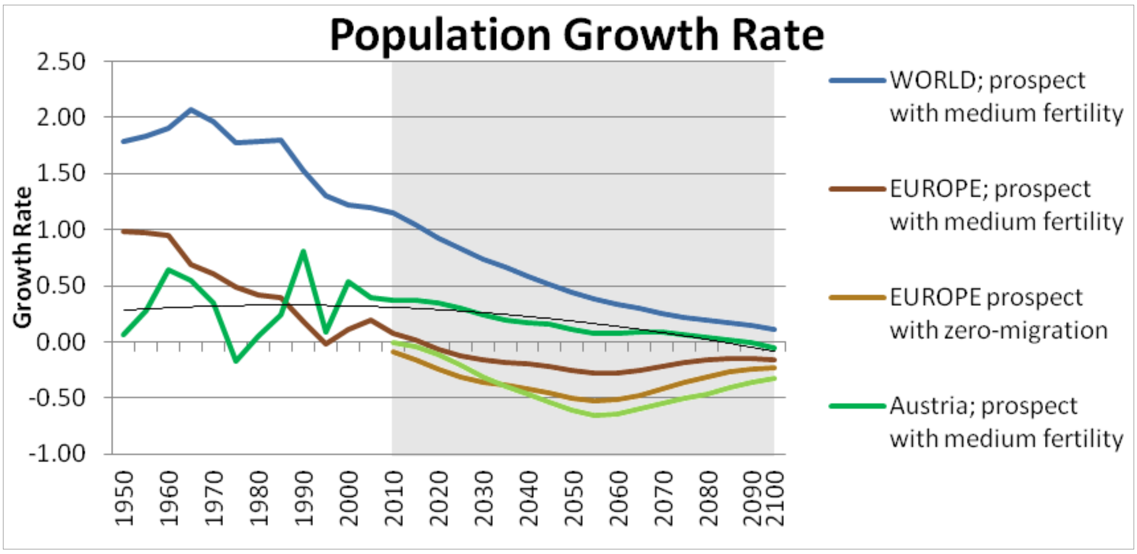



**Figure 21: Annual trend of population change for the whole World, Europe and Austria. From 2010 it shows the prospect according to different scenarios based on the UN World Population Prospect (own illustration based on data of United Nations, Department of Economic and Social Affairs, Population Division 2013, online).**

On a regional level population development faces more variability due to the many different short term changes taking place in the different regions. Figure 21 shows that the population growth rate of Europe is already close to zero and will probably decrease in the next decades in the scenario of a medium fertility rate. Austria experienced greater variability in the past and is expected to follow a trend of slowly increasing population which turns to a stagnation from the middle to the end of the 21st century.

The projections presented in Figure 21 show the importance of migration for the population growth in Europe and Austria: especially in the middle of this century the growth rate will fall if no migration takes place. For Austria these changes will be greater than for whole Europe.

The age distribution is also changing over the years. Muenz indicates that the age pyramid in Western and Central Europe is reversing due to a lowering fertility rate and a rising life expectancy (Muenz 2007, 5). Figure 22 shows the expected changes towards an older society. On the global level the changes from 1950 to 2000 mainly show a growing population in general. In the younger age groups a changing pattern can be seen that suggests a decreasing death rate. For 2100, the pattern changes significantly; all cohorts up to 40 years have a similar size and only a slow decrease in size can be seen of the cohorts above that age. The graphs for Europe and Austria show similar patterns but include more regional trends e.g. in the graphs for the year 2000 the baby-boom cohorts can be distinguished as bows around the age of 35.

## Population by Age

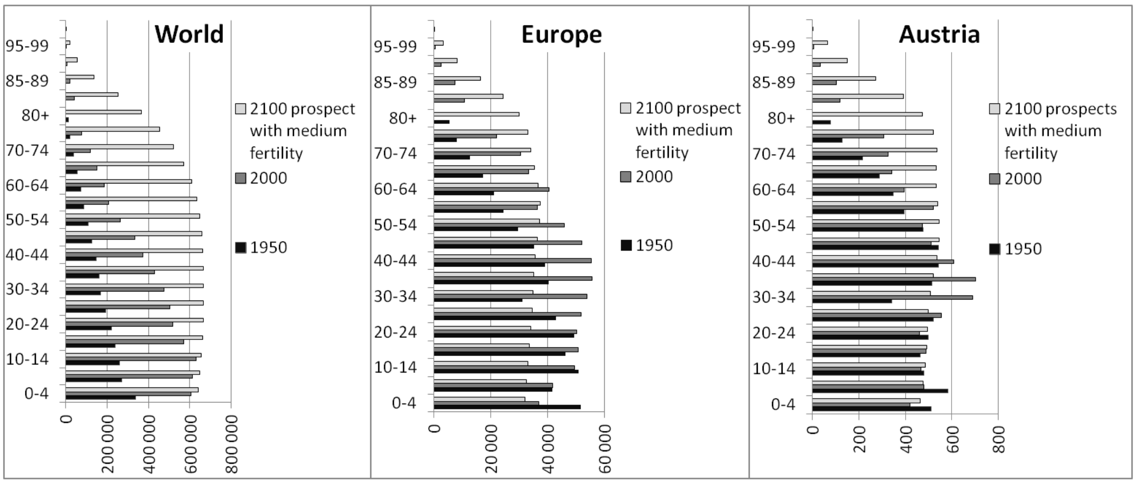



**Figure 22: Population pyramids for 1950, 2000 and the forecast for 2100 based on the UN World Population Prospect. Absolute numbers for the whole World, Europe and Austria in 1,000 (own illustration based on data of United Nations, Department of Economic and Social Affairs, Population Division 2013, online).**

The population of Vienna is growing in the last decades (from the 1990s to the 2010s) after a decline in the 1970s and 1980s. This growing trend is expected to continue according to the Statistik Austria prospects (2014). Figure 23 shows a future projection of the population of Vienna up to the year 2075. It also shows the division into age groups (younger than 20, 20 to 65 and older than 65 years). The group of older people is growing faster than the other groups similar to the national and European trend.

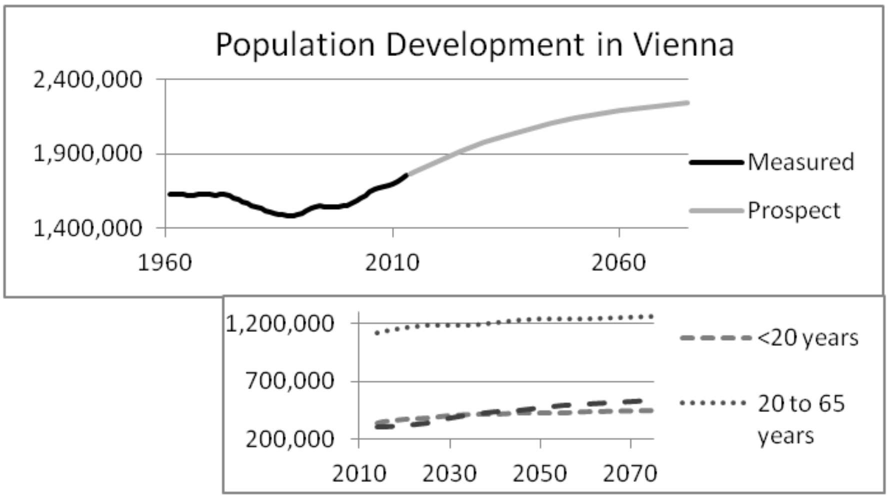



**Figure 23: Population development in Vienna. Top: Registered development from 1961 to 2013 and prospect to 2075. Bottom: Prospect from 2014 to 2075 in age groups (source: own illustration based on data from STATISTIK AUSTRIA 2013; STATISTIK AUSTRIA 2014)**

To summarize, Vienna is facing an aging population in the future consistent with the general trend mentioned above. This is important to analyse the future sensitivity of the population to heat stress.

A small scale forecast is needed for the analysis of the changes within the city. Therefore, data from the Department for Urban Development and Planning from the City of Vienna is used, which presents a population prospect for 2035.

The data is calculated based on prognoses for the natural changes of population (fertility, mortality and life expectancy) and on spatial changes (regional distribution, immigration from abroad, migration within the city, between the city and its surroundings and from and to other parts of Austria). Additionally the special conditions of inhabitants of institutions, of new development areas and naturalisation were considered for the population prospect. Clusters were made for all aspects to specify the behaviour of different regions. Clusters are developed by adding objects with high similarity (dependent on the topic) to the same cluster (Lebhart, Marik-Lebeck, and Klotz 2007).

The spatial resolution of the data is shown in Figure 24, which is a map of the current population density in Vienna. The units are based on registration district (Zählbezirke); additionally, they are separated or joined depending on their size. Vienna is divided into 262 analysis units and two analysis units for the surroundings of Vienna were added (Lebhart, Marik-Lebeck, and Klotz 2007, 10). A prospect on such a small scale is only solid for 10 to 15 years (ibid. 2007, 34). Afterwards (for the time frame up to 30 years) it only shows the approximate trend. For a long term trend (80 to 100 years) a prognosis on this level wouldn't be very meaningful due to inaccuracy (ibid.).

The small scale prospect shows a general growth of the population and also an increase in population that is in need of care. Vienna will most probably lose population to its surroundings but this can be compensated by immigration from abroad and other regions of Austria (Lebhart, Marik-Lebeck, and Klotz 2007, 37–40).

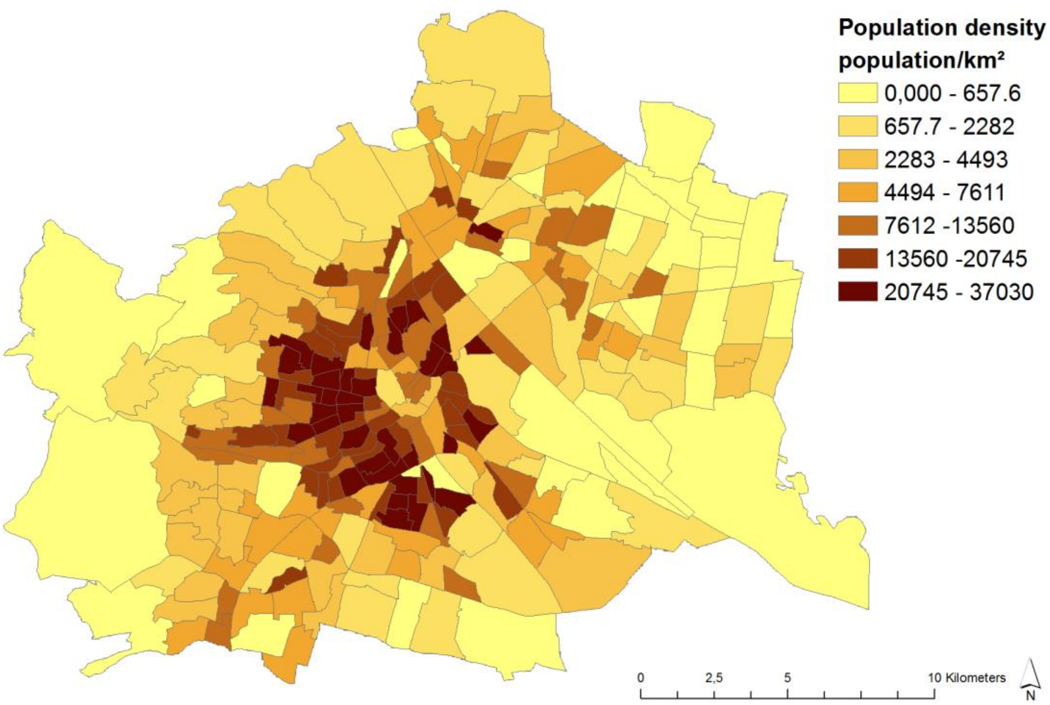



**Figure 24: Population density in Vienna 2005 (source: own illustration, data Stadt Wien/MA 18 2012).**

The data of this prospect can be used to evaluate the future sensitivity of the population of Vienna as it is the most detailed analysis on this small scale. It is thereby possible to see differences within the city. Additionally, the data provides different age groups: 0 to 14, 15 to 29, 30 to 44, 45 to 59 and older than 60 years. The age group of elderly people is thereby not as detailed as the data used for the sensitivity indicator in the baseline scenario, but there is still a differentiation by age. Therefore, this data is used for the future sensitivity.

The data does not include information about the distribution of female and male population. Therefore, it cannot be included in the analysis.

### ADAPTIVE CAPACITY

The simulations of adaptation measures by the urban fabric project are used as an indicator for the adaptive capacity. They are restricted to the densely built-up areas of Vienna. These are the urban fabric types 1 (industry), 2a (central block structures from the 19th century located on a slope), 2b (central block structures from the 19th century), 2c (extended city centre), 3a (urban expansion from the post-war period) and 3b (compact development of the urban expansion and old village centres). The type 2c (historic city centre) was not included in the simulations and will thereby approximated by the results for 2a and 2b because of their climatic similarity.

Figure 25 shows an example of these simulations with trees planted along the streets. Differences in the urban climate can be measured due to these trees. There are also significant differences whether the trees are on the west-east oriented streets or on the north-south oriented streets. The indicator for measuring the effects in this simulation is the Predicted Mean Vote (PMV), which is best around 0 and represents a warm or hot feeling when it is above 0. The results of the PMV presented in Figure 25 are calculated for the 14th of July 2001 at 3:00pm in 1.5m height from the ground to show the maximum thermal stress (Stiles et al. 2014, 7–1).

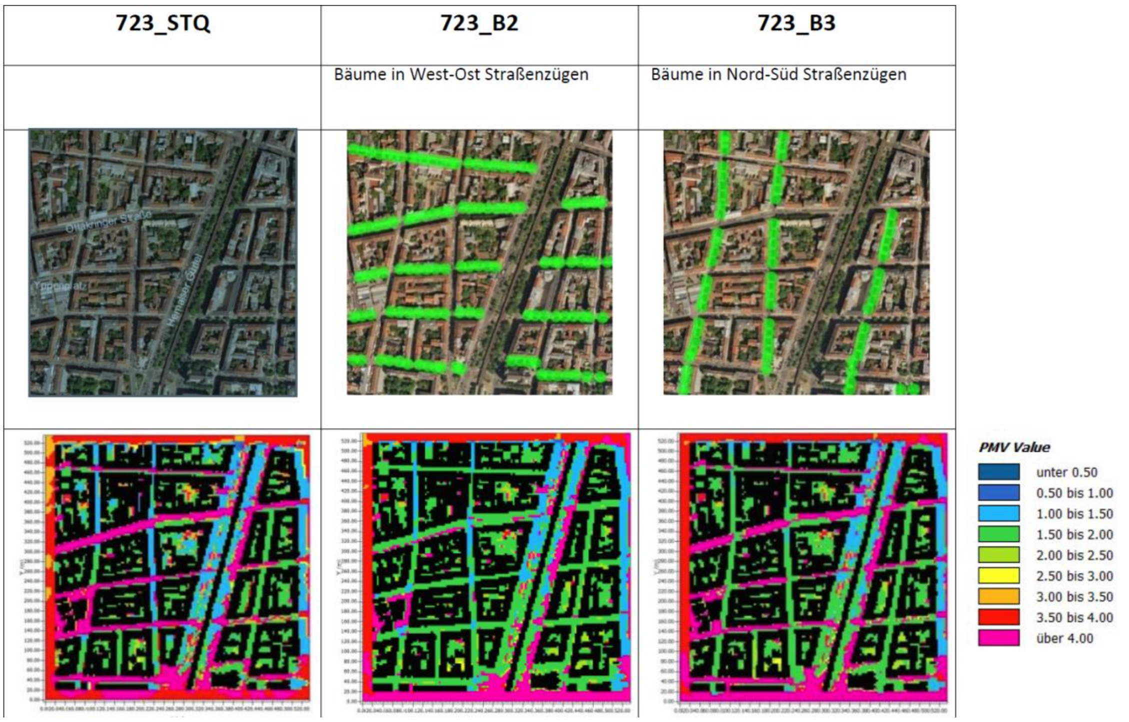



**Figure 25: Simulation of planning measures of the Urban Fabric Types project in one quadrant. Top: city structure and planned measures (trees on the streets). Bottom: urban climate effects (source: Stiles et al. 2014, 7–10).**

The project also combined different measures (see Stiles et al. 2014, 7). The results show what can be done in the different urban fabric types to adapt to heat. These results are summarised in Table 4. The measures are separated by the different open space structures on which they can be implemented. These simulation methods allow an estimation of climatic effects of planning measures.

| Urban Fabric Type | Open space structure | measures | local climate impact in summer | climatic impact on neighbouring areas in summer | potential implementation / surplus value | potential intensity of use | amount of area |
|---|---|---|---|---|---|---|---|
| 1 | parking area | TP+US | 1.00 | 1.00 | 1.00 | 1.00 | 0.13 |
| | green roofs (potential) | RG | 0.67 | 0.67 | 1.00 | 0.67 | 0.3 |
| | industrial area | TP+US | 0.67 | 0.67 | 0.33 | 0.33 | 0.3 |
| | street network | TP | 1.00 | 1.00 | 0.67 | 0.67 | 0.09 |
| 2a | street network | TP | 1.00 | 0.67 | 0.67 | 1.00 | 0.24 |
| | street widening | TP+US | 1.00 | 0.67 | 0.67 | 1.00 | 0.05 |
| | parking area | TP+US | 1.00 | 0.67 | 1.00 | 1.00 | 0.03 |
| | green roofs (potential) | RG | 0.67 | 0.33 | 0.67 | 0.67 | 0.09 |
| | courtyard | TP+US | 0.67 | 0.33 | 0.33 | 0.67 | 0.01 |
| 2b | street network | TP | 1.00 | 0.33 | 0.67 | 1.00 | 0.22 |
| | street widening | TP+US | 1.00 | 0.67 | 1.00 | 1.00 | 0.02 |
| | parking area | TP+US | 1.00 | 1.00 | 1.00 | 0.67 | 0.05 |
| | industrial area | TP+US | 0.33 | 0.67 | 0.33 | 0.33 | 0.05 |
| | courtyard | TP+US | 0.67 | 0.33 | 0.67 | 0.67 | 0.07 |
| 3a | green roofs (potential) | RG | 0.67 | 0.33 | 0.67 | 0.67 | 0.04 |
| | street network | TP | 1.00 | 0.67 | 1.00 | 0.67 | 0.12 |
| | parking area | TP+US | 1.00 | 1.00 | 1.00 | 0.67 | 0.02 |
| | industrial area | TP+US | 0.67 | 0.67 | 0.33 | 0.33 | 0.05 |
| 3b | street network | TP | 1.00 | 0.67 | 0.67 | 0.67 | 0.17 |
| | street junction | TP | 1.00 | 1.00 | 0.67 | 1.00 | 0.02 |
| | parking area | TP+US | 1.00 | 1.00 | 1.00 | 0.67 | 0.05 |
| | street widening | TP+US | 1.00 | 0.67 | 1.00 | 1.00 | 0.01 |
| | courtyard | TP+US | 0.67 | 0.33 | 0.33 | 0.67 | 0.13 |
| | green roofs (potential) | RG | 0.67 | 0.67 | 0.67 | 0.67 | 0.03 |

TP Tree Planting
US Unsealing
RG Roof Greening

**Table 4: Potential of adaptation measures for the different Urban Fabric Types (source: own illustration based on Stiles et al. 2014, 8--21)[18].**

These findings are used as indicator for the adaptive capacity. The local climate impact and the potential of implementation multiplied by the area are used for the particular quadrant.

Figure 26 presents city development areas with a strong increase in population. They are defined by a population growth rate >0.9 and a total population in 2035 >1000. A growth rate of 1 would represent a doubling of the population. The threshold of 0.9 is used to include all

[18] The original values ranged from 1 (low impact) to 3 (high impact). They were rescaled from 0 to 1 for comparability with other indicators.

areas that are nearly doubling in population. A high number of total population is used to include only the areas which are living areas.

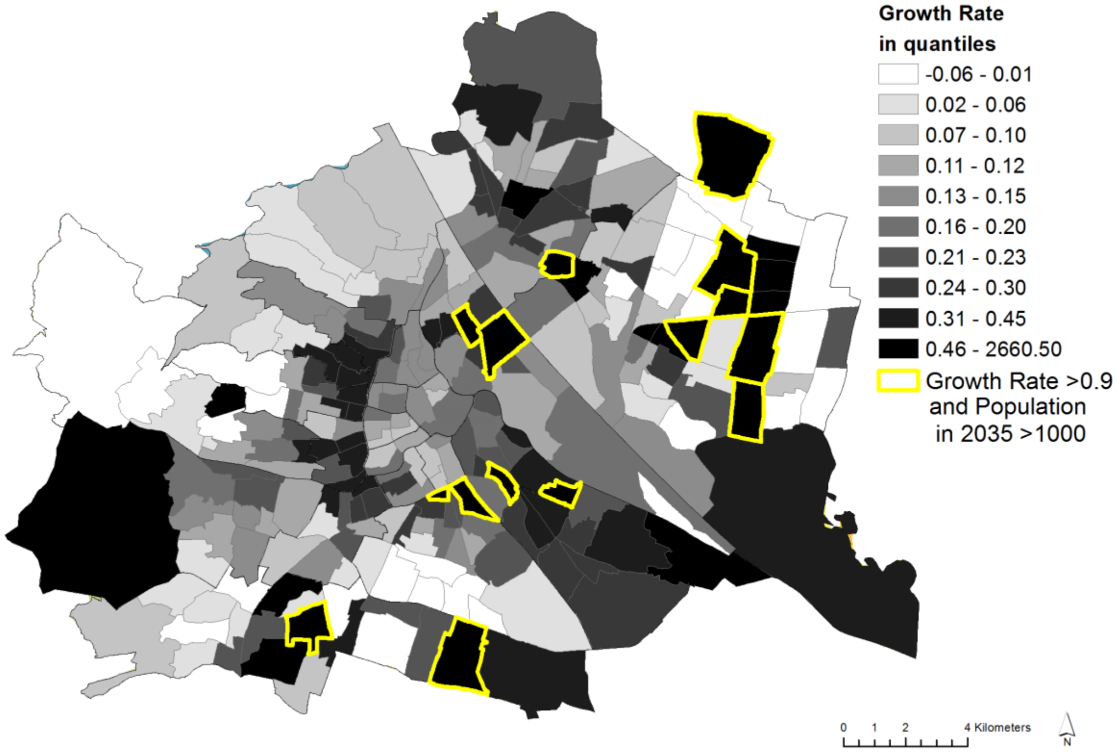



**Figure 26: City development areas with a high expected population growth[19] from 2005 to 2035 (source: own illustration data: Stadt Wien/MA 18 2012).**

All neighbourhoods marked in Figure 26 are defined as areas with a high development potential in the urban development plan 2025 (STEP 2025) of Vienna (Vienna City Administration 2014, 67). Other city development areas are not included for the adaptive capacity because a significant restructuring of a neighbourhood is needed to allow adaptation beyond the one defined by the urban fabric project. It is supposed that city development without increasing population (e.g. business districts) does not necessarily include a restructuring of the city structure. The value of adaptive capacity for these areas is set to 1 to approximate the fact that during the planning process a maximum amount of adaptation is possible. The urban structure and open spaces can be optimised in consideration of the heat load. The potential measures were summarised before in Table 4.

Table 5 summarises the data used for the future scenarios. The data for access to compensation areas and medical attendance are the same as in the baseline scenario.

| Indicator | Data Quality | Source |
| --- | --- | --- |
| Average summer days in Vienna | Scenario: according to the IPCC scenarios A1B, A2 and B1<br>Resolution: 100m | ZAMG (ZAMG 2013b) |

[19] The growth rate is calculated with $(t2 - t1)/t1$. If t1 = 0 the growth rate equals t2. A growth rate of 1 corresponds to a doubling in population.

| | | |
|---|---|---|
| Population density and age | Small scale population prospect for Vienna from 2005 to 2035<br>Resolution: analysis units based on registration districts (262 in Vienna) | Open Government Data Vienna 2012 (Stadt Wien/MA 18 2012) |
| Adaptive Capacity | Planning suggestions for Urban Fabric Types. Only for built up areas.<br>Resolution: 500m<br>City development areas | Project Urban Fabric Types[20] (Stiles et al. 2014)<br>Open Government Data Vienna / STEP 2025<br>(Stadt Wien/MA 18 2012) |

**Table 5: Indicators for the future scenarios of sensitivity and exposure (own illustration).**

The data is converted to allow comparison. The same approach as above is applied for this normalisation. Figure 27 and Figure 28 show this procedure for the population data of 2035 and the average summer days 2021-2050 in scenario A1B.

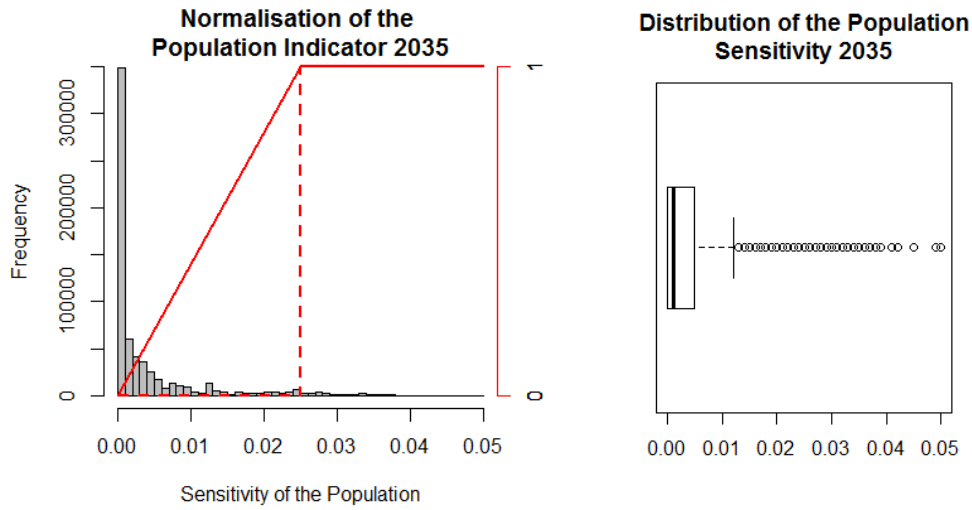



**Figure 27: Distribution and deviation of the population sensitivity in 2035. Left: Histogram and normalisation of the indicator. Right: Boxplot of the values (source: own illustration).**

The distribution of the population indicator (see Figure 27) shows less deviation than the population indicator of the baseline scenario due to the lower spatial resolution of the data. Thus, it is necessary to use data on the same spatial resolution in the baseline scenario for the direct comparison with the future scenario.

[20] TU Wien Institut für Städtebau, Landschaftsarchitektur und Entwerfen, Fachbereich für Landschaftsplanung und Gartenkunst; AIT Austrian Institute of Technology GmbH, Energy Department; TU München, Lehrstuhl für Strategie und Management der Landschaftsplanung; TU Wien Fachbereich Stadt- und Regionalforschung

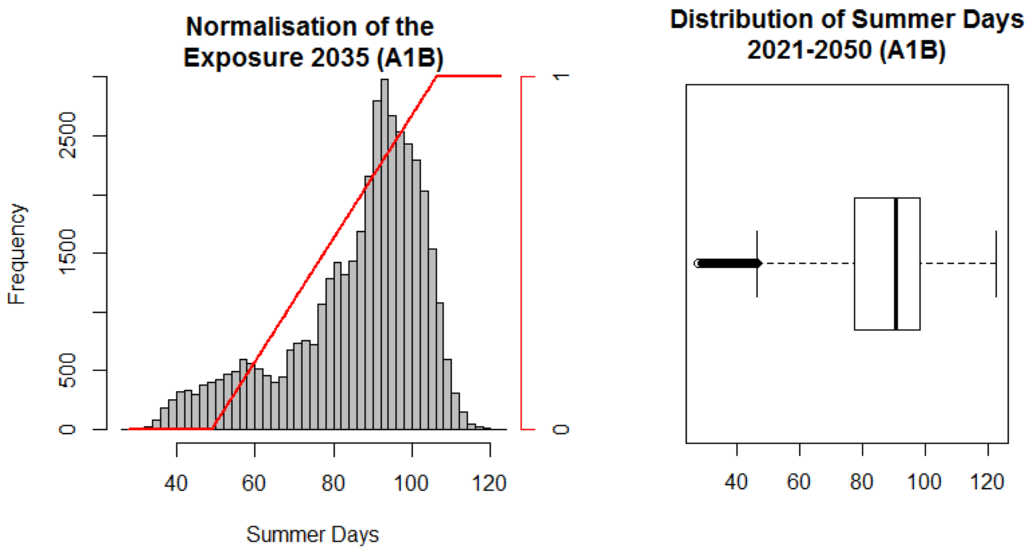



**Figure 28: Distribution and deviation of the exposure in the near future. Left: Histogram and normalisation of the indicator. Right: Boxplot of the values (source: own illustration).**

The number of summer days increases from the baseline scenario to 2021-2050 in the climate scenario A1B while the distribution shown in Figure 28 is similar to the one of the baseline indicator. The median of summer days in Vienna shifts from 79.1 (1971-2000) to 90.7 (2021-2050) in scenario A1B and 83.4 (2021-2050) in scenario A2. In the scenario B1 the number of summer days is relatively constant up to the middle of the century with a median of 79.5.

A normalisation of the data is not necessary for the indicator of the adaptive capacity because the data it is already in a comparable scale (see Table 4). The indicator is shown in Figure 29. The data is limited to densely built-up areas. The areas on the east of the Danube River and in the south of Vienna have in part (with the exception of the development areas) a low adaptive capacity. The central districts have a medium adaptive capacity. The industrial and commercial zones have a high adaptive capacity.

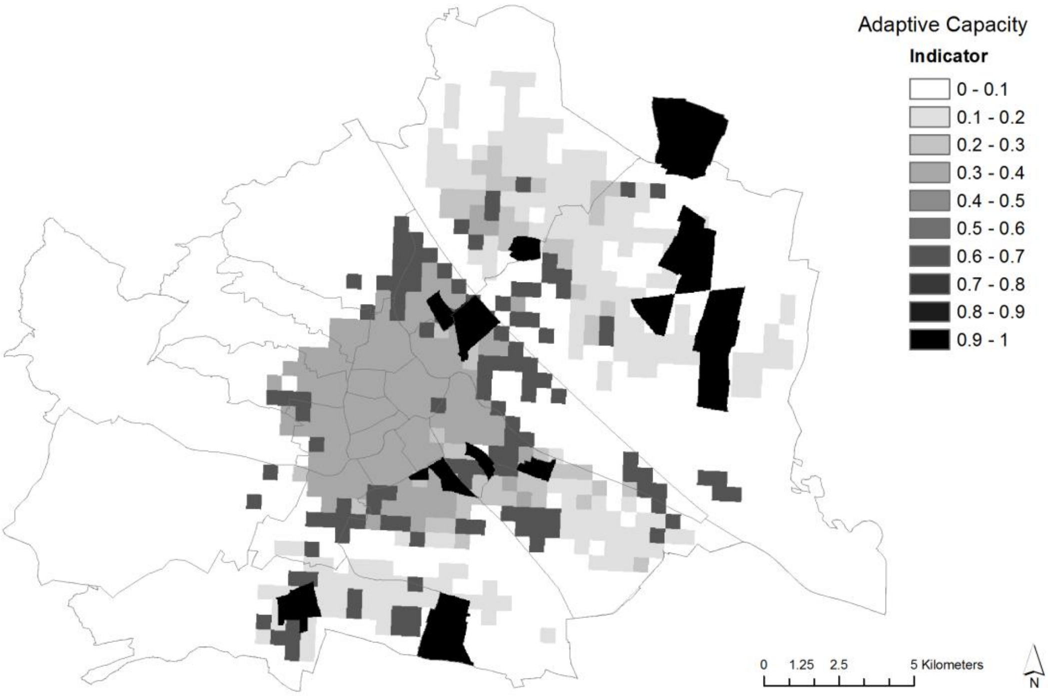



**Figure 29: Indicator for the Adaptive Capacity (source: own illustration).**

# 4 RESULTS

The situation of current heat stress and the comparison with the expected future are presented below. They are calculated with the indicators of exposure (number of summer days), sensitivity (population density, age distribution and distribution of male and female population, access to medical attendance and access to compensating areas) and adaptive capacity (potential of spatial planning interventions). The main results are additionally included in the appendix in a higher resolution.

## 4.1 BASELINE SCENARIO

The baseline scenario shows the situation of heat stress for the year 2000 based on climate information of the time frame 1971-2000[21].

For methodological reasons, no vulnerability exists for the baseline scenario, because vulnerability describes a future situation. The difference between impact and vulnerability is defined by the adaptive capacity; as all possible adaptations are already implemented in the current situation (because the adaptive capacity is already utilised), only the impact is presented for the baseline scenario. The current impact will then be compared with the future vulnerability.

### 4.1.1 IMPACT

The impact of heat stress describes the potential relative heat stress of an area compared to the rest of the city. The impact in the baseline scenario is shown in Figure 30. It is calculated by the product of sensitivity and exposure. Additionally, the appendix provides a map of the impact with the district boundaries of Vienna to facilitate the interpretation.

[21] The number of summer days in 2000 was not equal to the exposure data: the data is defined as average number of summer days in the time frame of 1971–2000. Thereby, the strong deviations of temperature within single years can be avoided.

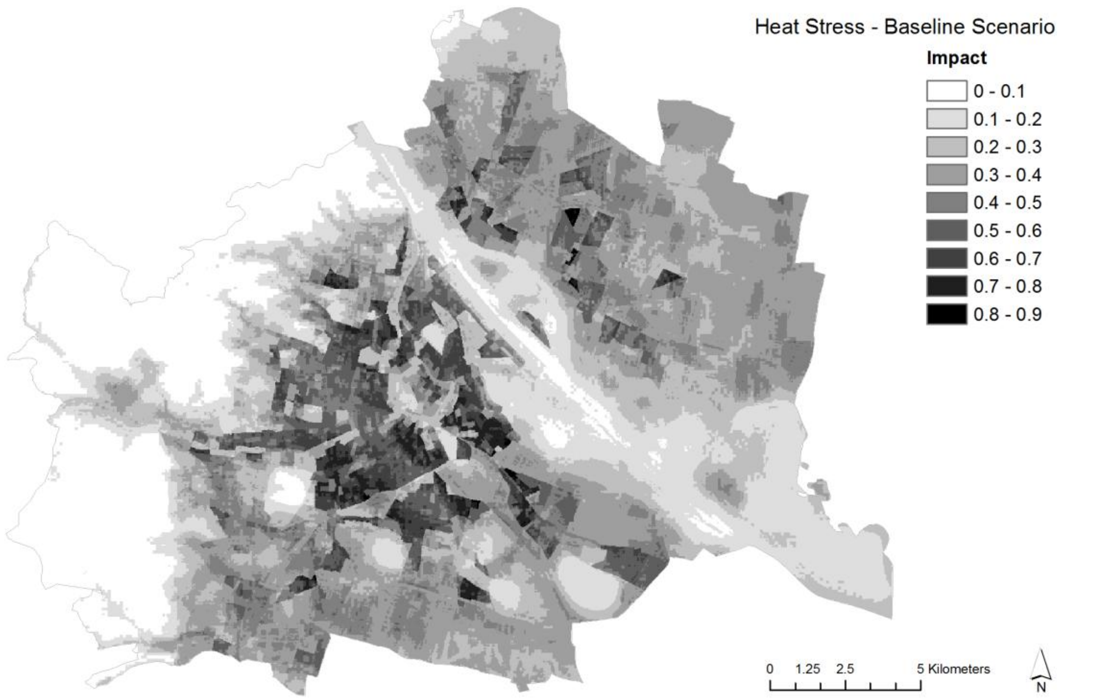



**Figure 30 Impact of heat stress in the baseline scenario. Dark areas are expected to have the highest impact (source: own illustration).**

The big recreational areas, green areas and water bodies are still visible because they have low values in all indicators except for the access to medical attendance. These areas face a low amount of heat exposure because the land use highly influences the microclimate. Vegetation (especially forest) produces fresh and cool air. Water bodies cool the air through evaporation. These effects go beyond the areas of forests and water bodies and affect neighbouring regions. These areas are not or only rarely populated. Thus, they have a low sensitivity to heat stress.

The city centre (the first district of Vienna) is not strongly affected by heat stress mainly due to a lower sensitivity compared to the area around the centre: it has a lower population density and a good medical infrastructure. In general, medical services are situated in residential areas but also in business areas and major centres due to their good accessibility. The population density and thereby the sensitivity is low in the quarters around the Ring Road. Additionally, due to the representational character of this neighbourhood there is a high number of parks and other open spaces within walking distance. The centre of the first district has a stronger heat impact than the area around the Ring Road because of a lower amount of compensating areas, a higher population density and a higher heat load.

The areas surrounding the first district face the highest impact due to high values in all indicators except for the access to medical services. A high number of sensitive population lives in these areas. Furthermore, they experience a high number of summer days[22] due to the dense building structure and the distance to the areas of cold air production. Although most parts of these districts face a high exposure, there are differences in the number of summer days. The 2$^{nd}$ and 20$^{th}$ district are strongly influenced by the Danube River and the Danube

[22] Summer days are defined as days with a maximum temperature of ≥25° (Žuvela-Aloise et al. 2013, 4).

Canal. The 3rd district and the north of the 11th district on the other hand have a high number of summer days although they are located close to the Prater as a major green space of Vienna. Due to the wind directions, the Prater has only marginal effects on these areas and cannot compensate the lack of green space within the districts. The darkest areas on the west side of the Danube (thereby excluding the 21st and 22nd district) are mainly areas with a high percentage of old buildings (cf. Stadt Wien 2014c).

The area around the train tracks going westwards is affected by a high impact due to the population sensitivity and the relatively high number of summer days despite its proximity to the Wienerwald. The dark areas in the south of the city can be explained by medium values in all indicators. These neighbourhoods are relatively far away from the big recreational areas and the green areas in the south are spatially limited in their influence because of the wind directions. Additionally, there are no large forests or water bodies. The density of the medical infrastructure is lower than in the city centre because of the generally lower population density in the south. However, there are still some neighbourhoods with a high population density and sensitivity. Therefore, they experience a higher impact.

The big train stations are visible as areas of low impact. There is no sensitive population because these areas do not include residential buildings. Additionally, the number of summer days is low due to the large open spaces: although the surface might experience a warming by solar radiation, the warmth can be easily transported to higher air layers. However, these open spaces have nearly no influence on surrounding areas. These spaces would need water bodies or a greater amount of vegetation to provide cooling for the neighbourhood [23]. Some of the big train stations are already closed and the areas are reused for residential and business buildings, so the impact on these areas might change in the future.

There are also some areas experiencing a high impact in the east of the Danube River. These are densely populated neighbourhoods, but they do not benefit from the Wienerwald and only marginally from the Danube River due to the main wind directions of Vienna. The unsealed areas in this region are mainly agricultural land and thereby do not have a strong influence in reducing the air temperature. Great parts of the 21st and the north-west of the 22nd district therefore have a high number of summer days. Additionally, these areas have a lower density of medical facilities according to the relatively low population density compared to the central districts.

The areas of Vienna that are actually occupied are shown in Figure 31. Most neighbourhoods that are affected by a high level of heat stress are residential areas. It can be assumed that the actual impact in these neighbourhoods might be even higher because the spatial reference of the population data is not limited to these areas.

The settlement areas are derived from the actual land use map of the City of Vienna. All areas that are used as living areas are merged together dependent on their distance to acquire the contiguous settlement structures.

[23] For more information on the cooling potential of different surfaces see section 2.3.2 Urban Heat Island Effect and Dobrovolný 2013, 95.

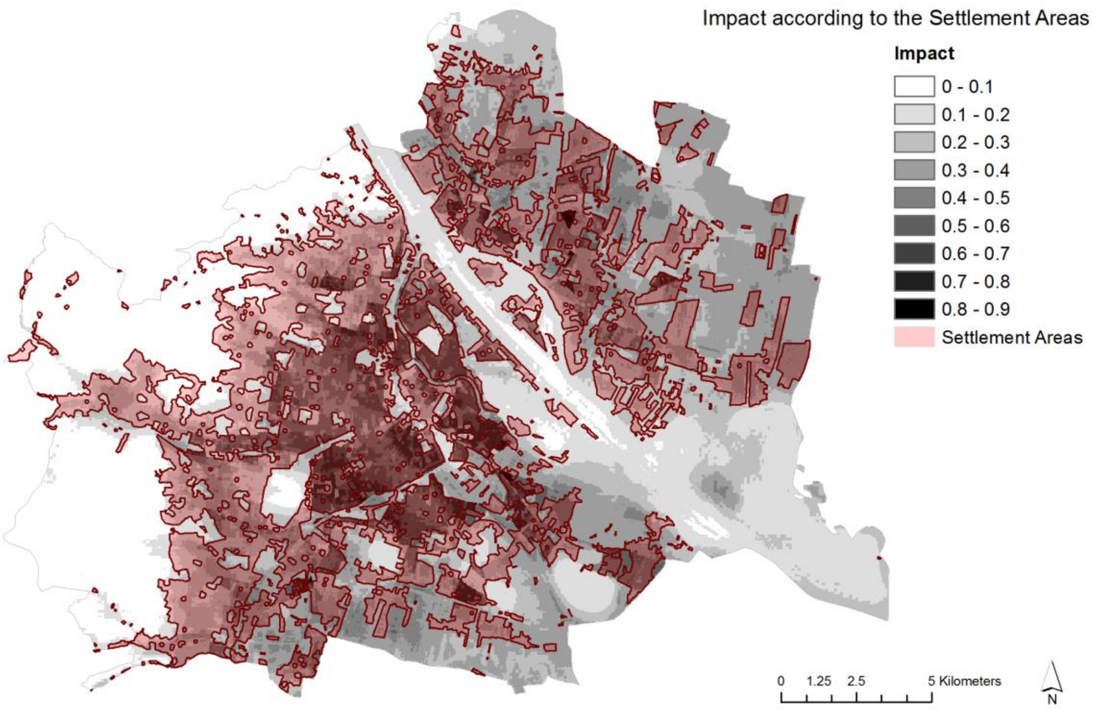



**Figure 31: Impact in the baseline scenario with highlighted settlement areas (source: own illustration).**

In summary, the impact in the baseline scenario is inhomogeneously distributed even in the urban areas of Vienna. Therefore, these areas need different approaches of intervention to decrease heat stress. The neighbourhoods which are affected by a high level of heat impact might be of special interest for planning intervention. However, the future development of this situation is of importance. In the next section the potential changes in the near and remote future are discussed to detect areas which need special attention.

## 4.2 Future Development – t1

The situation of heat stress in the near future is calculated for the time frame around the year 2035. The calculations include an inaccuracy, because the exposure (the number of summer days) does not include the changing urban structure. Thus, new urban development areas might be more vulnerable in the future than presented below.

### 4.2.1 Impact

The future impact is presented here to illustrate the future situation if no adaptation measures are implemented by 2035. Figure 32 shows the impact of heat stress in 2035 according to the global climate scenario A1B (see section 3.3.2 for the description of these scenarios). The maps with the impacts for the other climate scenarios are included in the appendix.

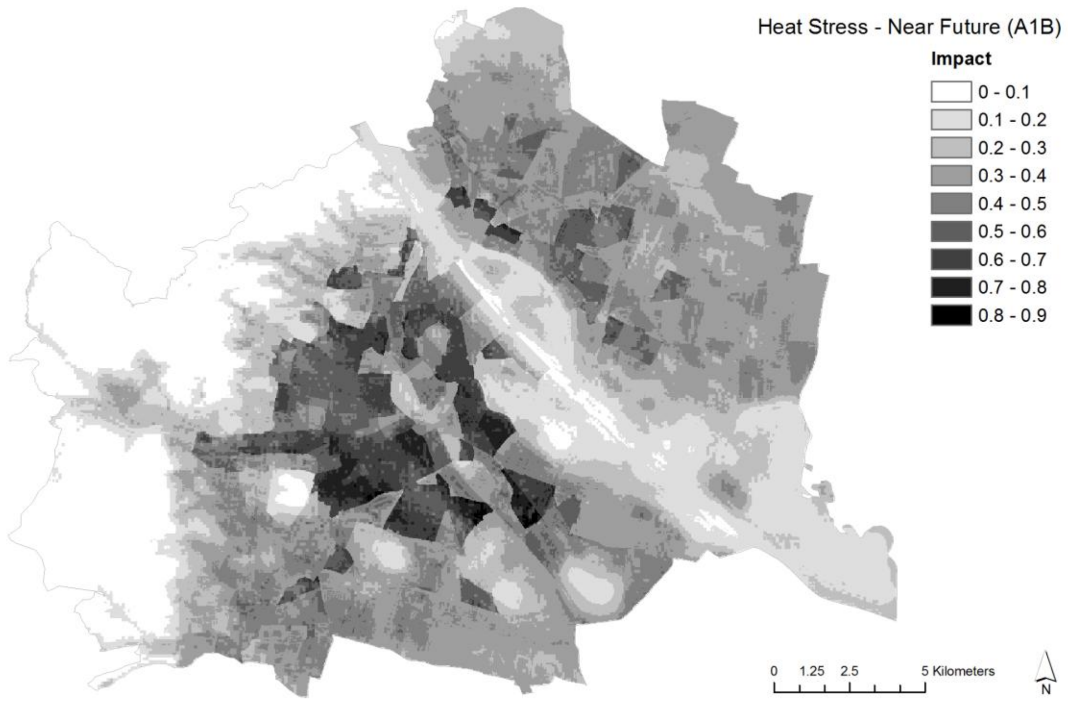



**Figure 32: Impact in t1 (2021-2050) in the climate scenario A1B (source: own illustration).**

The dark areas face a high impact and will therefore need measures to adapt to the heat stress. They are concentrated in the inner city with the exception of the city centre (1st district). The reasons for the high impact in these areas are similar to the description of the baseline scenario: they are densely built-up areas with a high population density. Due to this building structure there are only few open and green spaces. This urban space structure has a warming potential. However, the areas affected by heat are not limited to the inner city. In the districts across the Danube River (21st and 22nd district) many areas are affected by a medium to high heat stress impact.

The distribution of the impact does not vary significantly between the different climate scenarios. The differences between the scenarios (A1B, A2 and B1) are mainly in the amount of the heat exposure. The exposure is strongest in scenario A1B. This agrees with the general number of summer days according to the scenarios presented in 3.3.2 Future Scenario. In scenario A1B the highest number of summer days affects Vienna, in A2 less summer days are assumed and B1 creates the lowest exposure. Nevertheless, scenario A1B puts a special pressure on the 5th, 6th, 7th, 15th district and the inner parts of the 16th, 17th, 20th and 2nd district compared to the other scenarios. The differences in summer days between scenario A2 and B1 are concentrated on the built-up areas. Thus, the scenarios of high amount of warming affect particularly the urban areas of Vienna.

Figure 33 shows the differences between the impact of the baseline scenario and the near future impact to identify areas with a large amount of change. Positive values (red) signify a higher impact due to heat stress in the future, negative values (blue) show a reduced impact.

For the comparison with the current situation the baseline scenario was recalculated with the population on the same spatial resolution as the population prospect for 2035. This data is based on registration districts. The impact is calculated for every raster cell as a relative value in relation to the rest of the city. Thus, the comparison of the baseline and the future scenario does not show absolute changes of the heat stress but only the changes in the distribution.

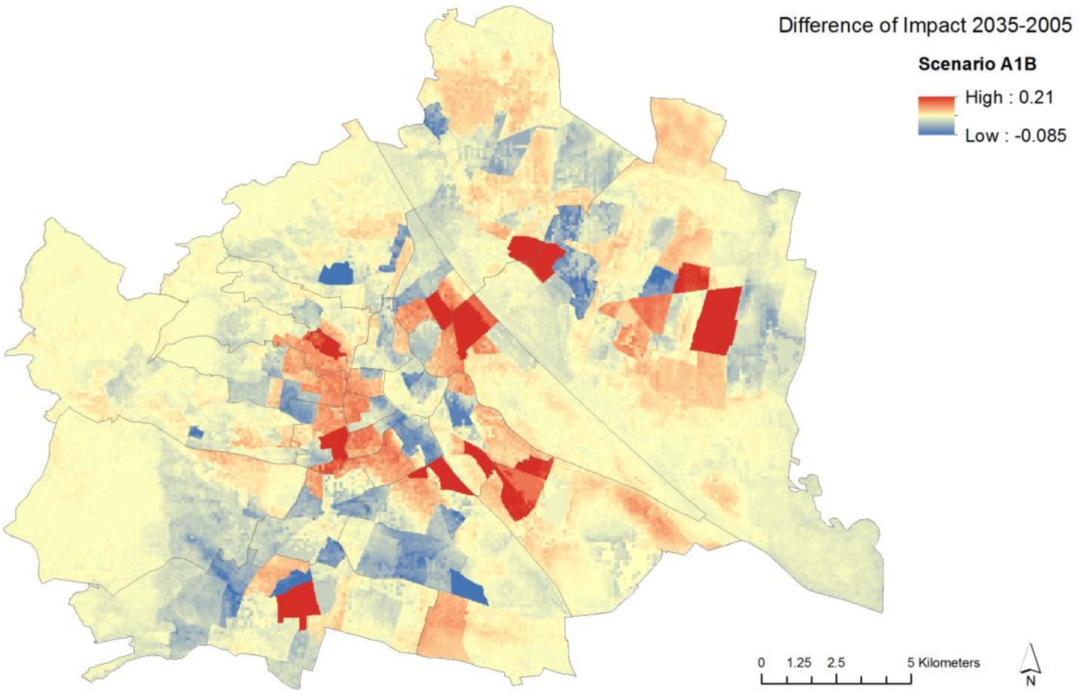



**Figure 33: Differences between the impact in 2005 and in 2035 in scenario A1B (source: own illustration).**

The patterns of the heat stress in 2035 differ from the pattern of 2000 mainly because of the changed population distribution. The red areas of Figure 33 show areas in which the heat stress increased significantly from 2000 to 2035. They are all areas with increasing population density and correspond to the city development areas.

The light red areas of Figure 33 can partially be explained by changes in the age distribution. This can be seen in Figure 34, which shows the rate of change of the elderly population between 2005 and 2035 and the absolute number of elderly inhabitants in 2035. The neighbourhoods of the $15^{th}$, $16^{th}$, $17^{th}$ and $18^{th}$ district which are near to the centre are expected to have a high percentage of inhabitants aged 60 and older in 2035. The increase in total population in these areas compared to the one in the new urban development areas is not particularly high. However, due to the population density, the increase in absolute numbers is high. Thereby, the sensitivity of the population increases.

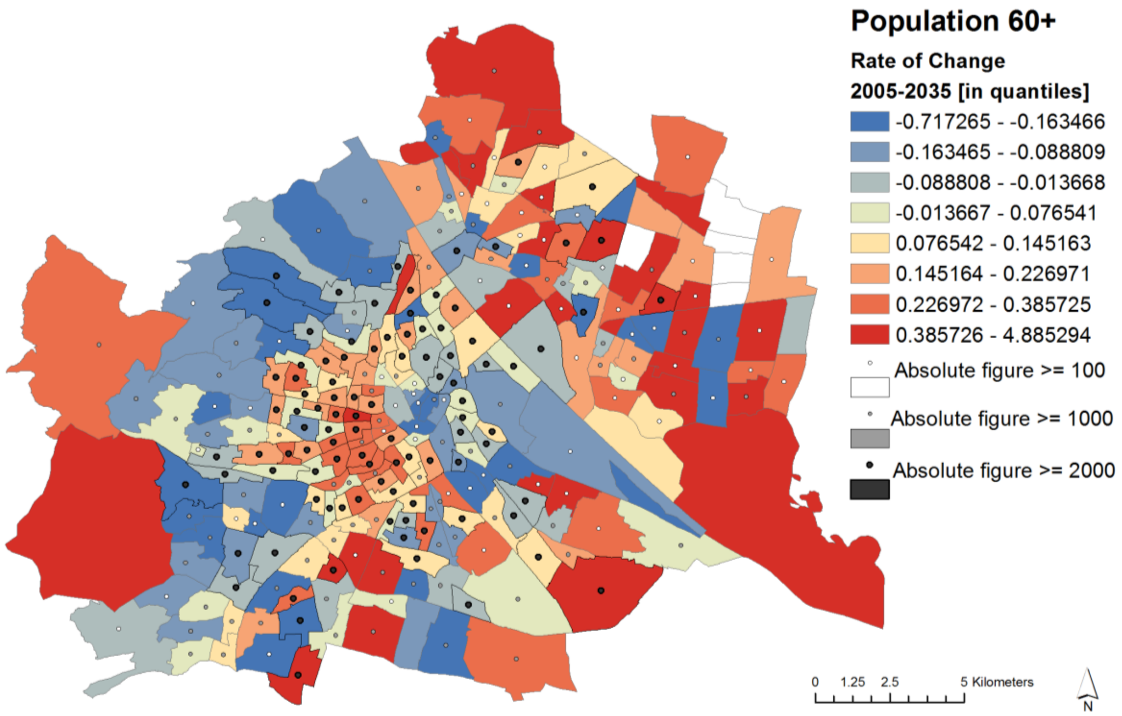



**Figure 34: Elderly population in 2035. The rate of change from 2005 to 2035 and absolute figures of 2035 (source: own illustration, data: Stadt Wien/MA 18 2012).**

Additionally, some changes due to the exposure are visible in Figure 33. Thus, the distribution of summer days will change within the city. These are for example the two light red clouds which range from north-west to south east around the city centre. These changing patterns in the number of summer days are particularly visible when comparing the situation nowadays with the end of the century. It is presented in section 4.3 in Figure 38.

### 4.2.2 Vulnerability

The vulnerability is only calculated for the densely built-up areas of Vienna, because the indicator of adaptive capacity only exists for these areas (see section 3.3 Scenarios).

Figure 35 shows the vulnerability in the climate scenario A1B (the scenario with the highest number of summer days). Positive numbers represent vulnerability to heat. Negative numbers show the potential to improve the current situation regarding to heat stress and measures leading to further improvement.

The differences in vulnerability between the three climate scenarios are similar to the differences in their impacts. The vulnerability is particularly low in future city development areas due to the high adaptive capacity. The new construction of a neighbourhood provides the possibility to include the knowledge of urban climate into the planning process and prevent an exceeding heat impact.

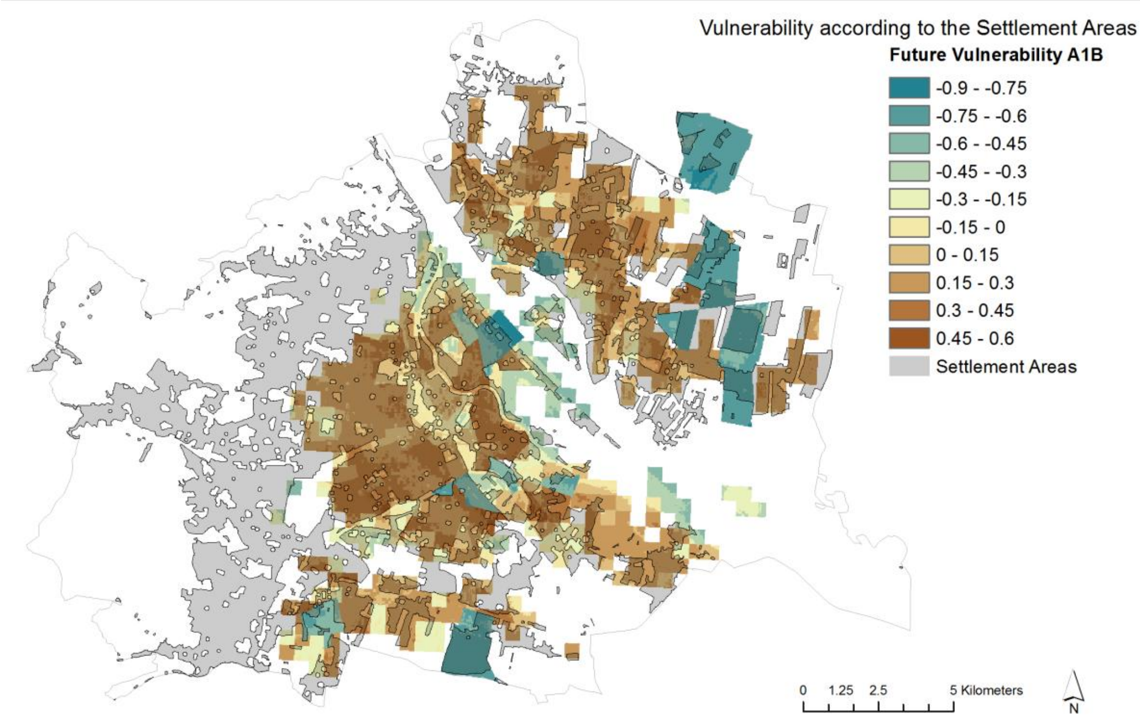



**Figure 35: Vulnerability in 2035 in the scenario A1B (source: own illustration).**

As mentioned above, areas with a high amount of green space and water expanse are less vulnerable to heat. They face a lower impact and thereby do not need much adaptation. This applies for example to the areas around the Ring Road, the Belvedere and the Augarten. They all have a high amount of vegetation and open space.

The neighbourhoods with an old building structure face a high level of future heat stress impact but they have a low adaptive capacity. It is probably not possible to cope with the changing climate situation in the short term by the means of spatial planning. In the long term, changes in the settlement structure or new areas of cold air production are possible as adaptation strategies.

Urban fabric type 1 (industrial and commercial zones) has a significant adaptive capacity to minimise the negative effects of the impact. These neighbourhoods have a high amount of area applicable for roof greening. Urban fabric type 2a[24], 2b[25] and 3b[26] are similar in their medium adaptive capacity (value of approximately 0.3). However, many of these neighbourhoods are vulnerable due to the strong heat impact. These are the districts surrounding the city centre, the central parts of the western districts and of the 3rd and the 10th district. Urban fabric type 3a[27] has a particularly low adaptive capacity: only few areas can be used for adaptation and not many measures can be realised here. Therefore, the South of Vienna, parts of the 11th, 21st and 22nd district (with exception of the development areas and green spaces) face a medium vulnerability.

[24] Late 19th century perimeter block development on sloping terrain
[25] Late 19th century inner urban perimeter block development
[26] Compact development in urban expansion areas and old village centres
[27] Post WWII urban expansion areas

Additionally, residential areas are shown in Figure 35. The changes in the settlement structure were assumed according to the expected population growth. It is thereby not an exact illustration of the future city development since exact data is not available for all of these neighbourhoods.

The vulnerable neighbourhoods presented in Figure 35 need additional measures beyond spatial planning adaptation, for example social and health care services. Additionally, long term planning could provide cooling through changes in the surrounding of these neighbourhoods by creating green areas.

The vulnerability decreases in all areas compared to the impact of the baseline scenario. Figure 36 shows the pattern of the impact 2005 minus the vulnerability 2035 in scenario A1B.

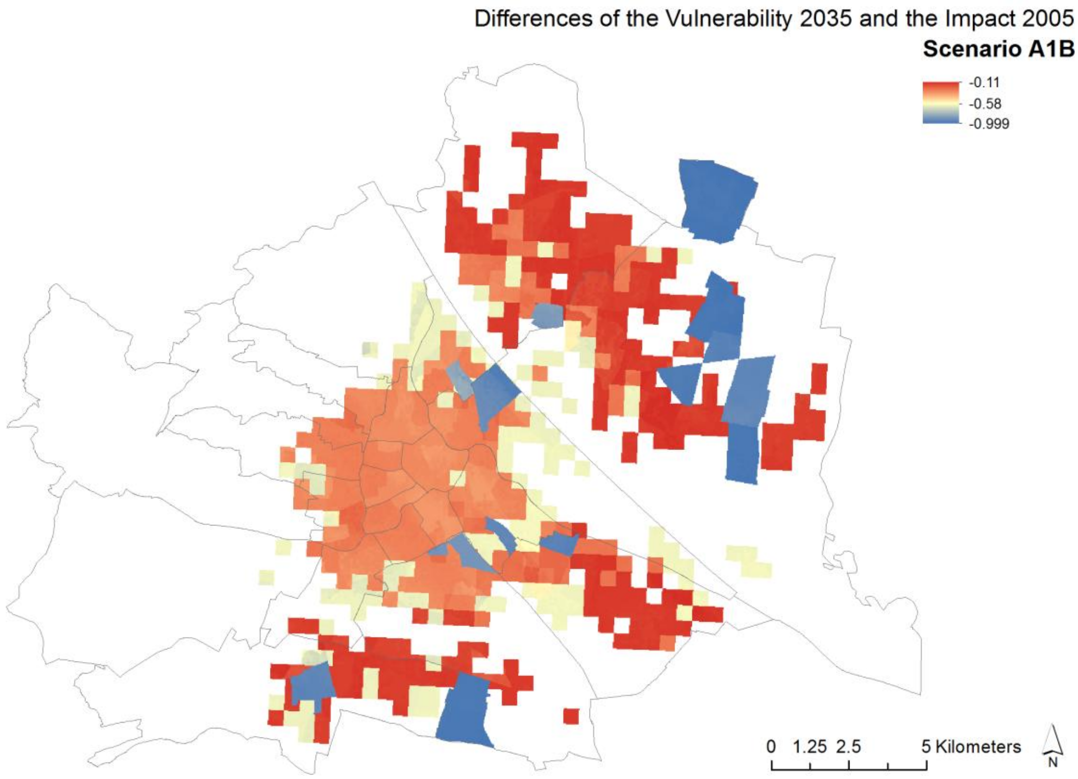



**Figure 36: Difference of the vulnerability of t1 and the impact of the baseline scenario (source: own illustration).**

Although the values are lower than zero, an improvement of the current situation is not certain. Figure 36 only shows the changing patterns. The absolute changes in exposure and sensitivity are not included in this calculation. Furthermore, the suggested adaptation measures might not be implemented. In the worst case of no adaptation at all, this would lead to the suggested impact presented above.

## 4.3 Future Development – T2

The vulnerability in the remote future (at the end of the century) cannot be calculated in the same way as for the near future. This is mainly due to the uncertainty of the population development: it is not possible to make predictions about the small scale distribution of the population for the remote future (80-100 years from now). Therefore, only descriptions of general changes in heat exposure and population sensitivity are provided below and no detailed vulnerability is calculated for this time frame.

The number of summer days is expected to increase up to the end of the century. Figure 37 shows the median of the different observations within Vienna. The number of summer days will increase in the whole city of Vienna. However, the summer days will be distributed unevenly within the city.

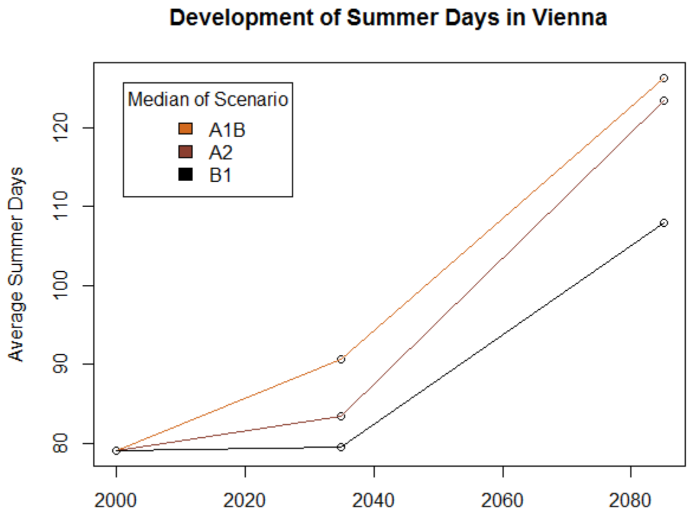



**Figure 37: Median of the number of summer days in Vienna from the 1971 to 2100in the different scenarios A1B, A2 and B2 [28](source: own illustration; data: ZAMG 2013b).**

Figure 38 shows the increase of summer days from the baseline scenario to the end of the century. The urban areas are the most affected ones. The need to adapt within the residential areas increases in order to minimise the negative effects for the population.

[28] The development of summer days between the years is not linear. The lines are only presented for a better visualization.

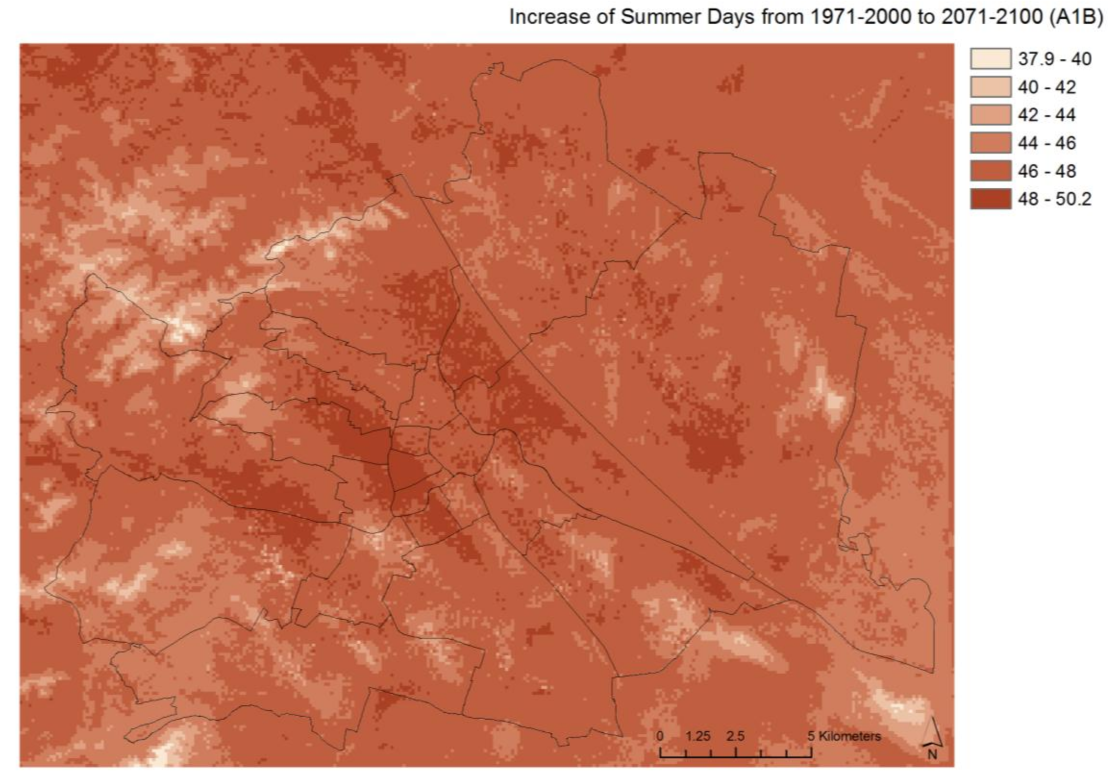



**Figure 38: Increase of summer days from the baseline scenario to the remote future(source: own illustration; data: ZAMG 2013b).**

Section 3.3.2 Future Scenario presented the population prospect of Vienna for the remote future (prospects are available up to the year 2075). In summary, it can be said that the population of Vienna will most probably increase. The number of people of age 65+ is expected to increase from 16.9% in 2012 to 23.9% in 2075 (Statistik Austria 2013). Thereby, the sensitivity of the population may increase in the future. However, the increasing life expectancy is also associated with an improved quality of life in the higher age groups. Therefore, the age groups that are most sensitive to heat might change over the years.

In the long term additional adaptation measures to the ones that defined the adaptive capacity in t1 are realisable. Changes in the urban structure and the creation of open spaces with increased vegetation might be useful in some areas. They are important for ventilation and the production of fresh air. Such measures influence a larger area beyond their particular implementation area. However, winds within the urban area might reduce the quality of open spaces. The urban structure has an influence on the wind velocity and street canyons may produce air turbulences (see Eliasson et al. 2006, 14).

The hypothesis of this research, which was made in the beginning[29], can partly be confirmed. Heat stress is unequally distributed in Vienna and also within the urban areas of the city. Due to the relative definition of vulnerability, it will not increase in general. However, the absolute number of summer days will most probably increase in the future. The changing

[29] The risk of heat stress related vulnerability is not equally distributed over Vienna and it will increase in the future due to the changing circumstances.

patterns of the vulnerability due to the age of the inhabitants and the old city structure with a low adaptive capacity lead to increased heat stress in the dense urban areas.

# 5 Discussion

The research showed that heat stress is a problem particularly in cities. The importance of heat will increase due to climate change in Central and Eastern European countries in the future.

A spatially detailed analysis of heat stress in Vienna with the theoretical concept of vulnerability was presented. Heat stress related vulnerability is based on the sensitivity of people, the exposure to climate stimuli and the adaptive capacity of the society to face challenges in the future. This research used different climate scenarios to measure the vulnerability to heat. This is important to show that the future impacts largely depend on human interventions amongst other influences.

The spatial planning interventions on the local level are considered as the adaptive capacity of the city. Thus, the comparison of the future impact and the vulnerability shows the different futures with and without adaptation. The knowledge about the possible future prospects of heat related vulnerability without adaptation can also serve as a guideline for political decisions; areas that are expected to experience a high impact of heat stress without adaptation may be improved by the spatial planning adaptation strategies provided above. Areas that are expected to be vulnerable in the future need additional strategies to cope with the heat stress. These strategies may include information campaigns or social and health care measures as for example the provision of air conditioned public buildings during heat waves.

The results demonstrate that heat stress is distributed unequally within the City of Vienna. The absolute number of summer days is increasing due to climate change particularly in the dense urban areas. The population of Vienna and the number of elderly inhabitants will most probably continue to increase. Therefore, the interventions to reduce the future heat stress are important. As mentioned above, it is possible that people adjust physically to the new situation over time. Additionally, the health care system may improve due to new medical research, but because of the speed of climate change adaptation of the built environment will most probably still be important.

This study focused on the negative effects of rising temperatures. However, the UHI effect contributes to a reduction of heat costs in winter and reduces energy consumption. Thereby, it lowers the contribution to climate change. Furthermore, the rising temperatures due to climate change are assumed to reduce the cold-related mortality (EEA 2012b, 189). Climate change is not a linear development. It has also positive effects for some regions occasionally. The contribution of climate change to heat stress in Central and Eastern Europe, however, has mainly negative results.

This research dealt with only one sector of climate change vulnerability. However, it is important to integrate different sectors into the planning of climate change adaptation and mitigation. Thereby, synergies between these sectors can be used and negative consequences in other fields of action can be prevented. This is particularly important for the coordination of adaptation to and mitigation of climate change for example by the reduction of the heat island of a city.

Attempts to reduce the heat island effect can in part act contrary to the concept of building compact settlement structures. This is the case if the attempt to reduce the UHI intensity by a lower building density leads to a scattered urban development. Furthermore, scattered settlements increase the amount of traffic and complicate the supply of health infrastructure. Thus, these policies have to be coordinated. Synergies exist for example in the lowering of the heat island effect and the reduction of flood risk: unsealed and green areas within the urban area improve the situation in both aspects.

## 5.1 Recommendations for Spatial Planning

The results of this study can be used for a differentiated implementation of spatial planning measures. In the neighbourhoods where a high future heat impact is expected measures like the increase of vegetation, the preservation of open spaces and shading are needed. Areas with no heat impact might be used for future city development and densification. However, these areas may have green structures with regional importance that have to be considered. Therefore, it is necessary to include an analysis of climatic consequences into the planning process.

On a regional level, the protection of forests for the production of fresh air, of water expanses for the cooling of air and of transport corridors for this air is important. The cooperation of municipalities and states is necessary to harmonise actions for example in the control of settlement developments. The regional aspect is particularly important because the continuous settlement structure does not end at the city border. The metropolitan area of Vienna includes communities in Lower Austria mainly in the north and the south of the city. Cooperation already exists in this region. For example, the PGO, which was already mentioned above, is an association to coordinate Vienna, Lower Austria and Burgenland in questions concerning spatial planning (PGO 2002, 2–3). Furthermore, the SUM (Stadt-Umland-Management)[30] is a coordination office for the regional development of the metropolitan area of Vienna (Hacker and Zuckerstätter-Semela 2014, 1). The focus on policies that are aware of heat as a future problem can be implemented on this strategic level.

Cooperation exists particularly for ecological reasons. For example, the States of Lower Austria and Vienna declared the Wienerwald as a UNESCO biosphere reserve (Biosphärenpark Wienerwald Management 2015). The protection of the forest limits the possibilities for settlements. In Lower Austria this is implemented by settlement frontiers: the state of Lower Austria is capable of enacting settlement frontiers to protect the landscape and the regional settlement structure (NÖ ROG § 1). Such instruments could also be used for the protection of fresh air corridors. However, problems may occur when municipalities have to limit their area of influence for the benefit of regional air corridors without these municipalities profiting from the air corridors themselves. Thus, the awareness of heat as a public concern needs to be raised in order to facilitate the realisation of climate-sensitive agreements.

The approach to protect such areas in form of intercommunal agreements on an informal basis is therefore relevant. On the municipality level, regional planning instruments like the SUM coordinate the planning interventions of Vienna and its surrounding communities. Regional planning concepts and projects are made in the scope of this cooperation. However,

[30] Regional management for Vienna and its surrounding communities.

they do not deal with heat and urban climate (see e.g. Hacker and Zuckerstätter-Semela 2014; Hacker and Zuckerstätter-Semela 2015).

Heat is not yet a general aspect of the regional planning coordination of Vienna and Lower Austria. Further information may increase the awareness and provide tools for the implementation of adaptation measures on this level. For example, the regional climate effects of development areas can be simulated by the FOCUS-I model of the ZAMG. It simulates climatic indicators for the whole city region based on different land use patterns. This tool could be used in the creation of development plans of communities to prevent negative climate effects on the surroundings in an early stage.

The questions of heat in the urban development of a growing city like Vienna differ from those in a shrinking city. More and more land is needed for buildings due to the increasing population. Urban sprawl could destroy green areas in the city region and increase the traffic; however, the prevention of urban sprawl and the prevention of increased heat stress because of dense neighbourhoods are in part contradictory. New green spaces within the urban area reduce the building density and may lead to urban sprawl. Thus, the arrangement and quality of green spaces in the limited space within a city are crucial to maximise the thermal effect. The amount of thermal effect depends on the ventilation which is determined by the structure and geographical location of a city. However, the thermal aspect is only one aspect of green areas: the recreational and social functions are important particularly in public parks. Thus, such aspects have to be included in the planning of green spaces. Changes in the urban structure are only possible in the long term. Interventions in already existing structures are difficult because they have strong impacts on the inhabitants. Therefore, heat should already be considered in the planning process for development areas.

In Vienna, the strategic orientation of spatial planning is defined by the City Development Plan (STEP - Stadtentwicklungsplan). The STEP05 mentions the climatic importance of green spaces and fresh air corridors (Vienna City Administration 2005, 167). The focus on the aspect “heat” has increased up to the STEP 2025. One target of green space within the STEP 2025 is defined as “urban greenery instead of air conditioning” (Vienna City Administration 2014, 117). The improvement of the city climate is an integrative part of this strategy.

The STEP 2025 suggests measures for climate change adaptation in the field of urban climate: the preservation of fresh air corridors, the reduction of sealed area, shadowing and the increase in vegetation (Vienna City Administration 2014, 117). Guidelines for the implementation of the strategy will be provided by the UHI-Strategy Vienna (Czachs et al. 2013). The information of this project may simplify the implementation of adaptation to increasing heat.

Large scale interventions in the existing built-up city structure will most probably not be able in the next decades. For example, the STEP 2025 mentions the importance of fresh air corridors (Vienna City Administration 2014, 117). The most important corridors are the Danube River and the Wien valley. The other air corridors are mainly limited to areas with a low building density (see Vienna City Administration 2014, 123) and may therefore not be capable of transporting fresh air into the densely built-up city centre. The air corridor between the Bisamberg (in the north of Vienna) and the 21$^{st}$ district may be of particular importance because of the expected urban development in the 21$^{st}$ and 22$^{nd}$ district in the future. The heat load is already high in the 21st district, thus, this air corridor has to be preserved. An intensification of its climatic impact would be necessary. The same applies for the air corridor in the south-east of Vienna (11th district) because of the existing heat load and population density.

However, the old building structure of Vienna cannot be changed in the short and medium term. It will most probably not be possible to create new air corridors or green spaces in the existing building structure within the next decades because of the excessive negative effects on the population (for example the loss of dwellings) and the costs of such restructuring measures. In the next years, the focus of adaptation strategies within the densely built-up areas will therefore be on a variety of smaller measures like the greening of buildings.

The expected climate effects of adaptation measures on a small scale can be simulated with the microclimate simulation model ENVI-met as it was done in the Urban Fabric Types project presented above. Such methods can also be used in the creation of the land use and development plan (Flächenwidmungs- und Bebauungsplan) to define allowed building structures. The building regulations of Vienna define the process of creation and changes of the land use and development plan (Bauordnung für Wien § 2). It would be possible to include the obligation to verify climatic impacts of changes of the land use and development plan in the building regulations. The land use and development plan is a legal binding document and is defined for the whole City of Vienna. Adaptation measures can therefore be implemented efficiently in this instrument. The basis for this integration already exists in the building regulations: it is for example possible (but not obligatory) to define the allowed structure of buildings, an obligation to enable vegetation and the greening of roofs (Bauordnung für Wien § 5).

Furthermore, the focus on green infrastructure and thereby heat reduction may increase due to the tool “local green plan” which is introduced in the “green and open space concept” as a part of the STEP 2025 (Stadt Wien/MA 18 2015, 32, 81–82). It is a standardised tool for the survey and the planning of green space. Therefore, 12 open space types (linear and planar ones) are defined within the “green and open space concept” (ibid.). This information is a basis for enabling a sufficient supply with open space within the planning process (ibid.). For example, the local green plan „Hirschstettner Hauptallee“ describes the existing green network and defines local measures to complete this network (Stadt Wien/MA 21 2014, 5–13). It is the basis for the land use and development plan (ibid., 20). The impact of this tool remains to be seen in the next years.

On the local level different aspects are important in the planning process. The implementation of measures needs the involvement of the inhabitants and other persons concerned to balance different interests. The measures to reduce the heat exposure in areas, which experience a severe impact, were summarised above. They include for example the planting of trees and the greening of roofs. Seasonal aspects have to be considered in the implementation of such measures. Shading for example is desired in summer but not in winter. This aspect can be considered for the choice of tree species to be planted. Moreover, the effects of these measures depend on the particular situation.

Apart from hierarchical spatial planning measures economic incentives can facilitate the implementation of climate sensitive planning. Such instruments of implementing measures to reduce the UHI are residential building subsidies. Urban climate could be included as one aspect in the guidelines for these subsidies. Additionally, information is important to raise the awareness of private owners.

Neighbourhoods that are expected to have a high vulnerability in the future can most probably not adapt sufficiently to climate change with the presented measures of spatial planning. Further strategies have to be developed. The vulnerability may be reduced by institutional measures of adaptation as for example social facilities and information campaigns. The findings can be used in the planning of social and health infrastructure. Neighbourhoods with expected future heat vulnerability should be prioritised for new facilities to reduce the risk of heat stress. However, a differentiation of the quality of the facilities would be important for a further analysis.

Further research may improve the information on the urban heat island and possible adaptation strategies. Such information can be the basis for planning decisions.

## 5.2 Limitations of the Research

The concept of vulnerability in the context of climate change underlies continuous development. Different indicators are used to define sensitivity, exposure and adaptive capacity. The ways to calculate vulnerability vary too. Therefore, different studies of vulnerability are not easily comparable with each other. Due to the complexity of the term vulnerability it is often not possible to access all required data. Thus, it is often necessary to approximate this term with the available data. This was also the case for this study where it was not possible to include social and financial aspects of the population.

The function of vulnerability was described by $V = S * E - AC$. However, different approaches exist in the literature to represent vulnerability. This approach requires a limitation in the input data for applicable results. Here, a range of 0 to 1 was chosen. 1 represents the maximum in comparison to the rest of the analysis region. Thus, negative values would represent an improvement. The possibility of improvement by climate change was excluded in this analysis.

The function contains an implicit weighting of sensitivity, exposure and adaptive capacity to vulnerability. However, this is only an approximation because of the limited knowledge of their interdependencies.

The assumption of a linear development of the indicators is only an approximation. The marginal utility for example of additional medical services may not be sufficiently described by the linear function. The knowledge of useful functions to describe the increasing sensitivity by an increase in population density, however, is limited. The same accounts for the exposure.

This research is based on models for the consideration of the future. Thereby, the results always include some part of uncertainty. The presented results cannot show exact information on a detailed scale but they show a general trend. Neighbourhoods which will most probably be affected adversely by heat in the future could be detected. The conclusions are relevant for a general future strategy of urban planning.

This study does not include the quality of medical facilities as for example public /private facilities, opening hours and offered services. Further research, which concentrates on the role of medical services, could include these considerations. They are important for health care strategies and the planning of new facilities. It was also not possible to include the new strategies of health care of the City of Vienna like the “Spitalskonzept 2030” due to its complexity and the low amount of available information.

A further study would be necessary to use the metropolitan area of Vienna as the analysis unit. It was mentioned above that a greater area may be useful for the analysis due to the connections of Vienna and its surrounding communities. However, this study was limited to the City of Vienna because of the differences in data quality.

It would be necessary to include the future urban development into the calculation of future heat exposure to provide more accurate information about the future heat stress in Vienna, because the urban structure significantly influences the local temperature. However, this data were not available for this study. The future heat exposure may be more severe than presented because open areas will in part be converted to built-up areas.

It was not possible to approximate the indoor temperatures. However, indoor temperatures are an important issue, because many people stay at home during heat waves. Particularly bedridden people may be at risk of heat stress. The relation of outdoor and indoor temperatures depends on a variety of factors that cannot be transferred easily from one city to another. Detailed information on the housing quality would be necessary for this analysis. Such information could be combined with the results of this study to identify areas of interest for renovations.

It was not possible to answer the question of the appropriate scale of research completely. This study tried to use data with the highest spatial resolution available. However, measurements of microclimate can vary significantly within a neighbourhood and not all outliers are of interest in a study on a whole city. Thus, the available data on a 100x100m resolution seemed appropriate.

Population data only consider people in their home. It may be useful to additionally integrate places with a high density of people (for example workplaces, schools, public transport and important squares) as sensitive locations. Such information may be more important for the quality of the results than population data on a higher spatial resolution.

The presented concept of assessing climate change is limited to the sector of heat. However, a combination of this concept with other sectors of adaptation may improve the quality of the results because interdependencies can be taken into account.

These open questions may be useful to gain more detailed information on heat stress in Vienna and thereby support adaptation strategies. Additionally, concepts of assessing climate change vulnerability may be improved. Due to the climate change and its impacts further research on this topic will become more important.

# APPENDIX

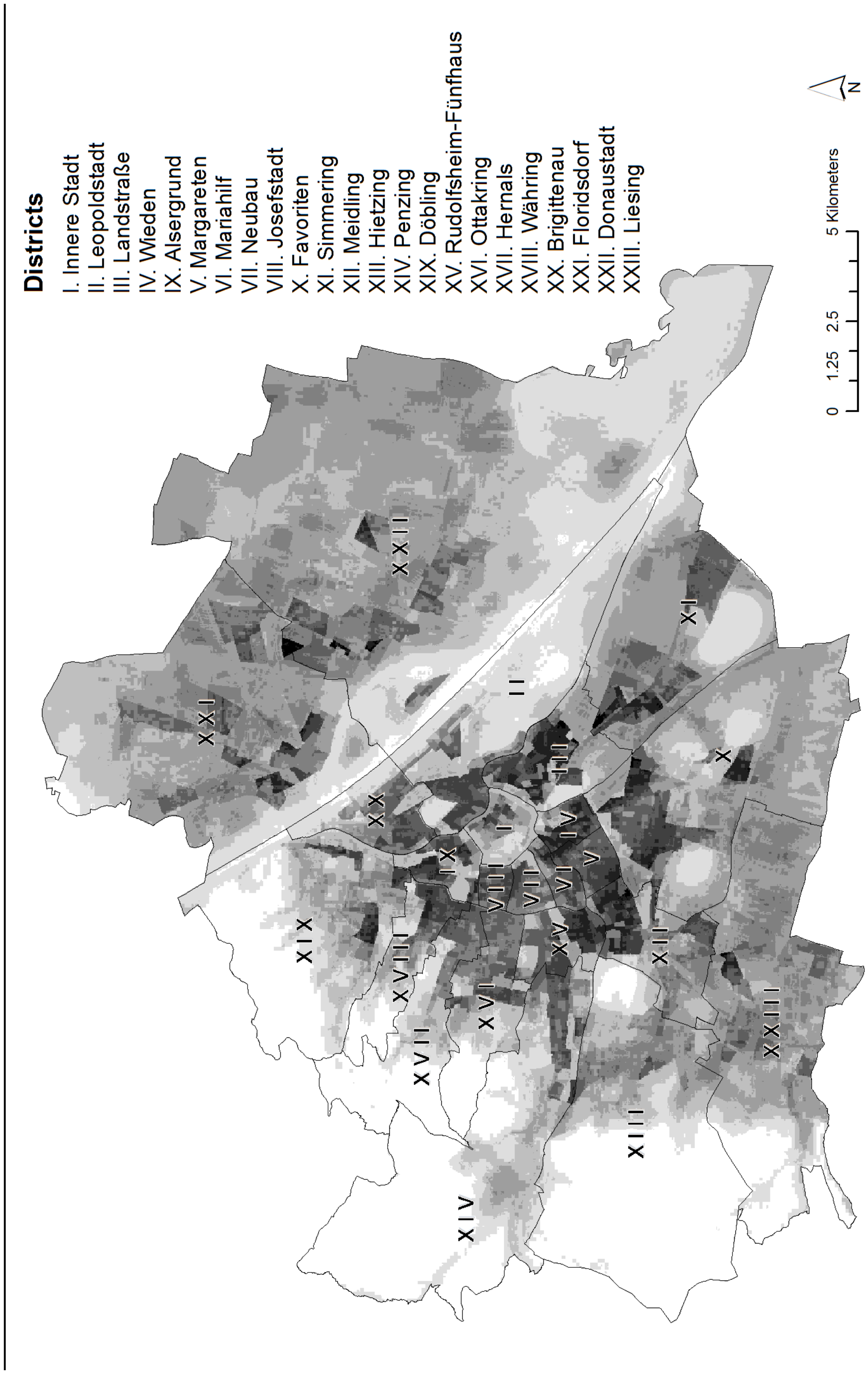



**Figure 39: Impact in the baseline scenario.**


**Figure 40: Impact with settlement areas.**


**Figure 41: Future impact – scenario A2.**


**Figure 42: Future impact – scenario B1.**

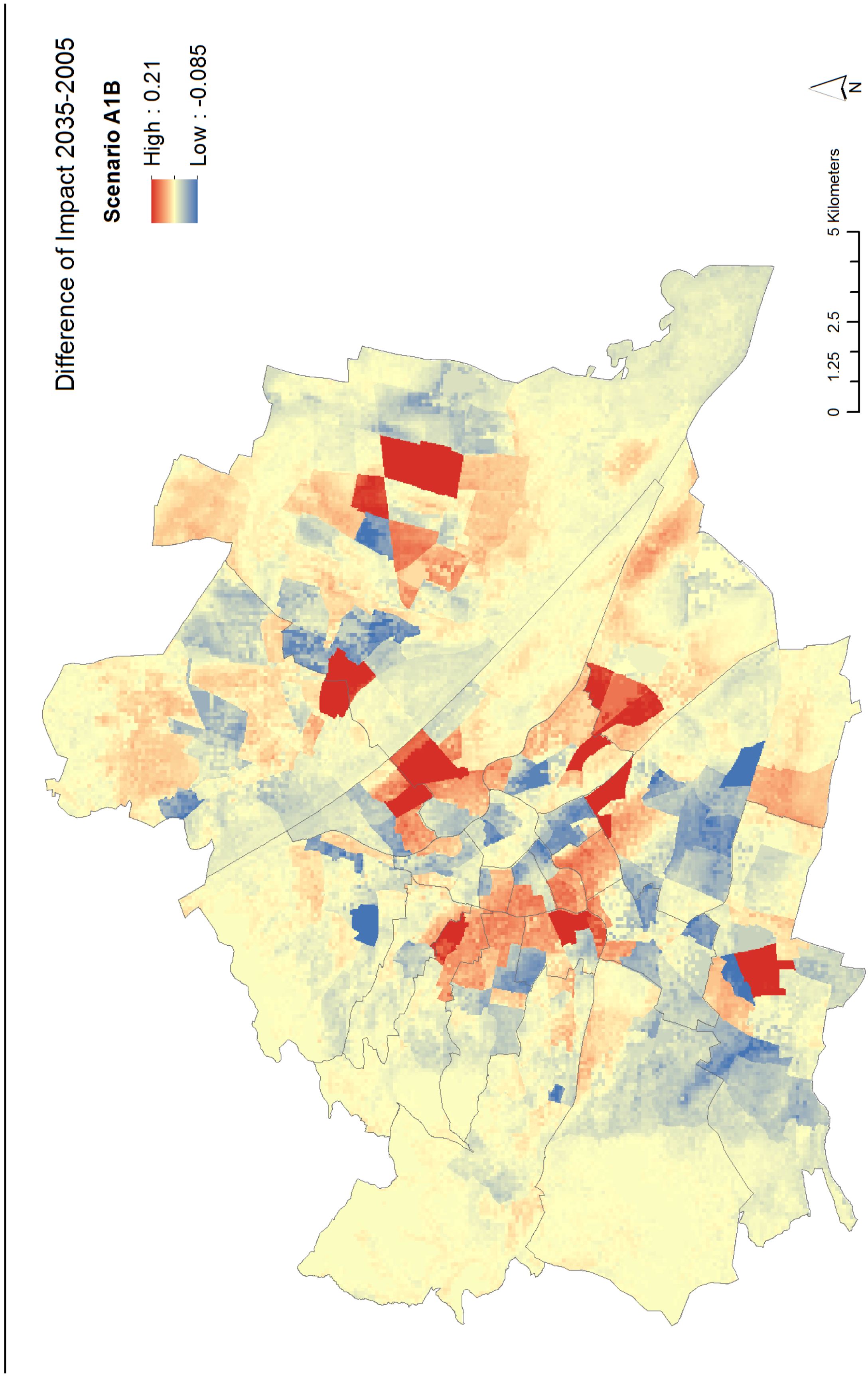



**Figure 43: Differences between the impact 2005 and 2035, scenario A1B.**

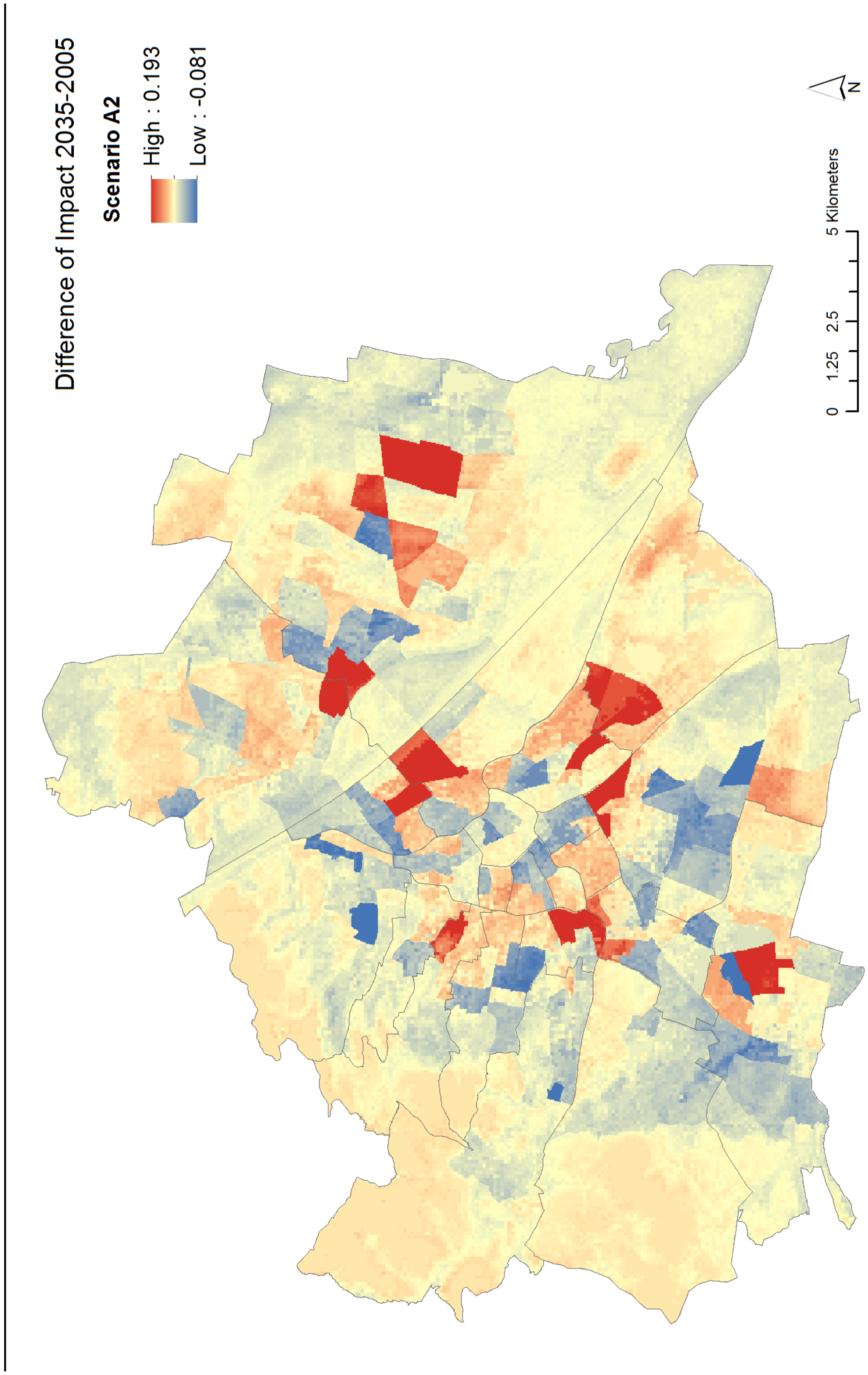



**Figure 44: Differences between the impact 2005 and 2035, scenario A2.**

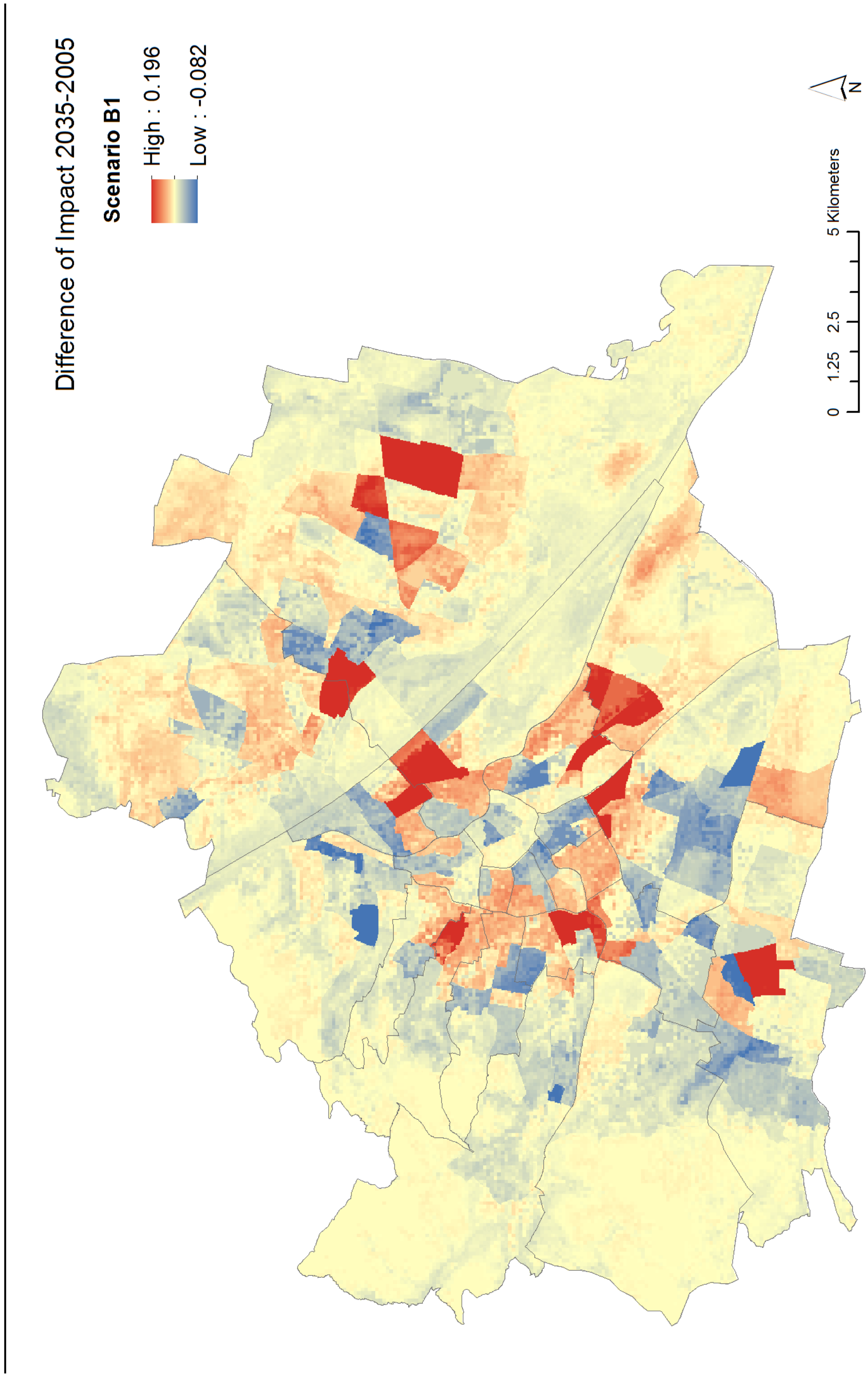



**Figure 45: Differences between the impact 2005 and 2035, scenario B1.**

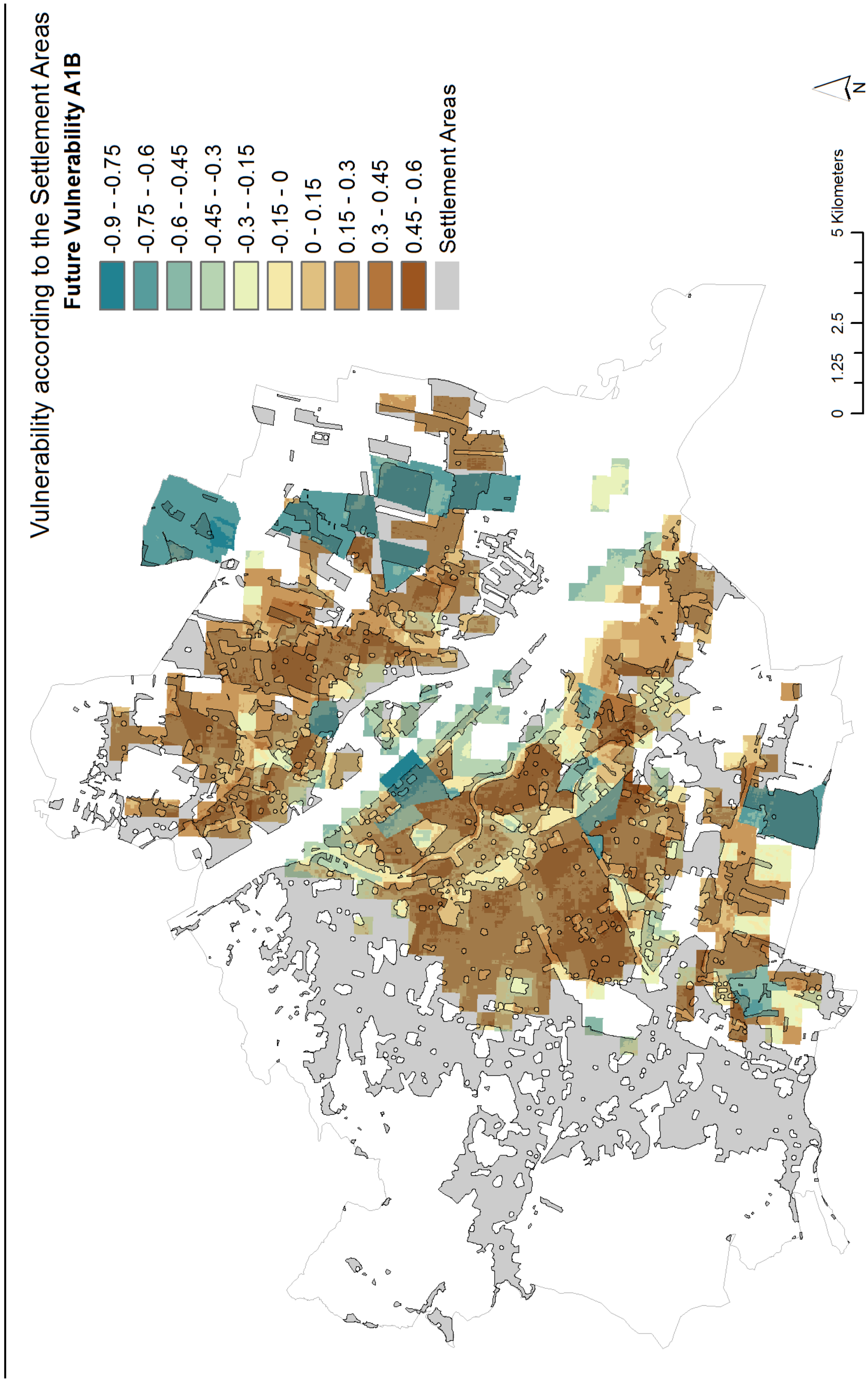



**Figure 46: Future Vulnerability (scenario A1B) with settlement structure.**

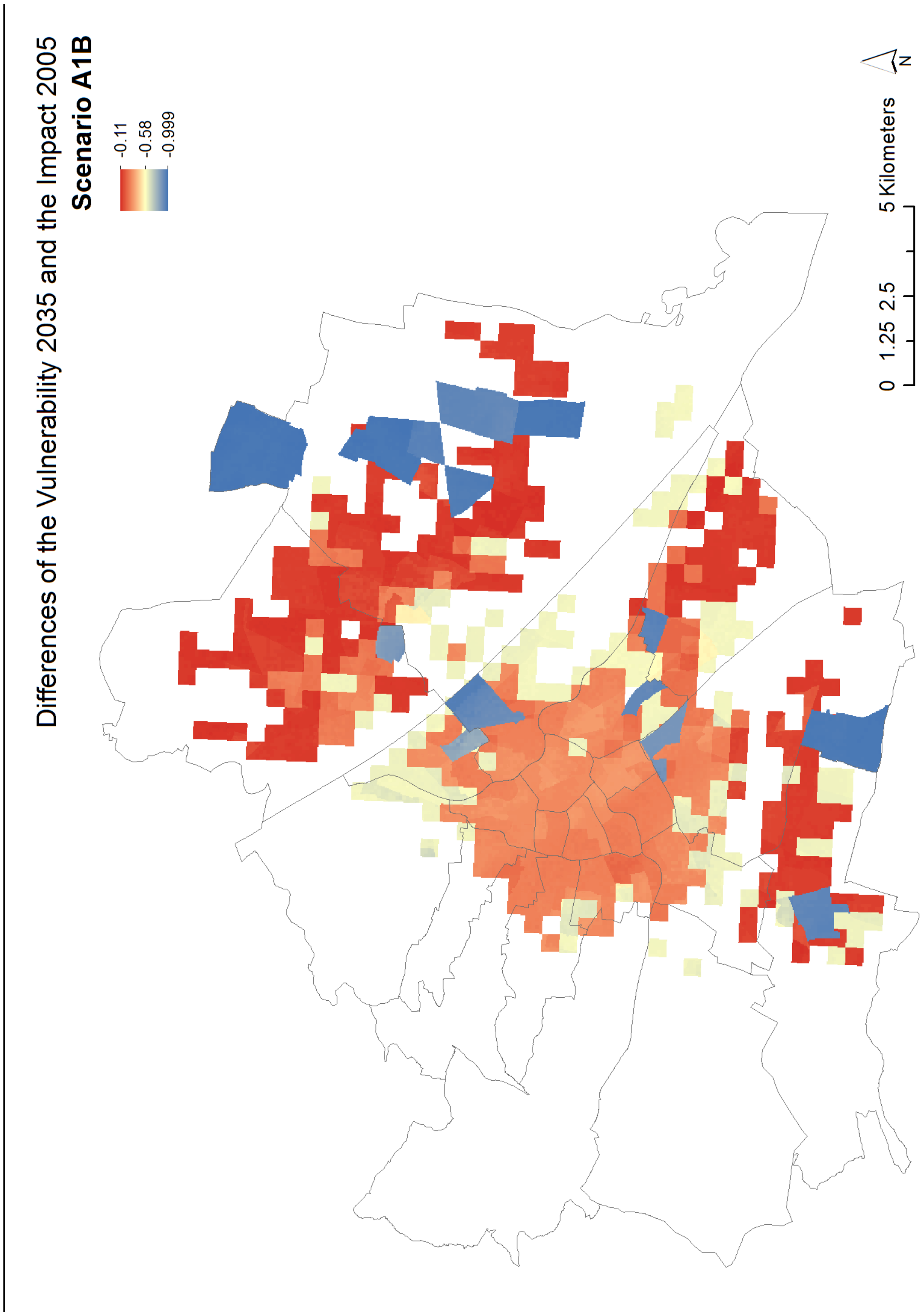



**Figure 47: Differences of t1 and the baseline scenario.**

# SOURCES


Adger, W. Neil. 2006. “Vulnerability.” *Global Environmental Change* 16 (3): 268–81. doi:10.1016/j.gloenvcha.2006.02.006.

Arnell, N. W., Matthew JL Livermore, Sari Kovats, Peter E. Levy, Rob Nicholls, Martin L. Parry, and Stuart R. Gaffin. 2004. “Climate and Socio-Economic Scenarios for Global-Scale Climate Change Impacts Assessments: Characterising the SRES Storylines.” *Global Environmental Change* 14 (1): 3–20.

Austrian Energy Agency. 2013. *Fortschrittsbericht Über Die Umsetzung Des Klimaschutzprogramms (KliP) Der Stadt Wien*. Wien.

Baccini, Michela, Annibale Biggeri, Gabriele Accetta, Tom Kosatsky, Klea Katsouyanni, Antonis Analitis, H. Ross Anderson, Luigi Bisanti, Daniela D’Ippoliti, and Jana Danova. 2008. “Heat Effects on Mortality in 15 European Cities.” *Epidemiology* 19 (5): 711–19.

Bauordnung für Wien (Wiener Stadtentwicklungs-, Stadtplanungs- und Baugesetzbuch), LGBl. Nr. 11/1930 idF. LGBl. Nr. 25/2014.

Biosphärenpark Wienerwald Management. 2015. “Wienerwald Facts : Biosphärenpark Wienerwald.” Accessed February 22. www.bpww.at/biosphaerenpark/biosphaerenpark-wienerwald-facts.

Birkmann, Jörn. 2013. “Measuring Vulnerability to Promote Disaster-Resilient Societies and to Enhance Adaptation: Discussion of Conceptual Frameworks and Definitions.” *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies (second Edition)*, 9–79.

Birkmann, Jörn, Hans Reiner Böhm, Frank Buchholz, Dirk Büscher, Achim Daschkeit, Sebastian Ebert, Mark Fleischhauer, et al. 2013. “Glossar Klimawandel Und Raumentwicklung.” http://d-nb.info/103111162X/34.

Bohannon, Richard W. 1997. “Comfortable and Maximum Walking Speed of Adults Aged 20—79 Years: Reference Values and Determinants.” *Age and Ageing* 26 (1): 15–19.

Bouchama, A. 2007. “Thermophysiology, Pathophysiology and Clinical Management of Heat Related Illness.” *Riyadh, King Faisal Specialist Hospital and Research Centre*.

Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, and Menne B. 2007. “Prognostic Factors in Heat Wave–related Deaths: A Meta-Analysis.” *Archives of Internal Medicine* 167 (20): 2170–76. doi:10.1001/archinte.167.20.ira70009.

Breuer, L., and H. Frede. 2003. “PlaPaDa - an Online Plant Parameter Data Drill for Eco-Hydrological Modelling Approaches.” http://www.staff.uni-giessen.de/~gh1461/plapada/lai/lai.html.

Czachs, Christina, Florian Reinwald, Doris Damyanovic, Christiane Brandenburg, Birgit Gantner, Brigitte Allex, Jürgen Preiss, and Ursula Liebl. 2013. “Urban Heat Islands–Strategy Plan Vienna.” *REAL CORP 2013*.

Demant, Bernd. 1993. *Fuzzy-Theorie oder die Faszination des Vagen: Grundlagen einer präzisen Theorie des Unpräzisen für Mathematiker, Informatiker und Ingenieure*. Braunschweig; Wiesbaden: Vieweg.

Dobrovolný, Petr. 2013. “The Surface Urban Heat Island in the City of Brno (Czech Republic) Derived from Land Surface Temperatures and Selected Reasons for Its Spatial Variability.” *Theoretical and Applied Climatology* 112 (1-2): 89–98. doi:10.1007/s00704-012-0717-8.

EEA. 2010. *Mapping the Impacts of Natural Hazards and Technological Accidents in Europe — European Environment Agency (EEA)*. Publication. http://www.eea.europa.eu/publications/mapping-the-impacts-of-natural.

———. 2012a. *Climate Change, Impacts and Vulnerability in Europe 2012 — Summary*. Publication. http://www.eea.europa.eu//publications/climate-impacts-and-vulnerability-2012.

———. 2012b. *Climate Change, Impacts and Vulnerability in Europe 2012*. Publication. http://www.eea.europa.eu//publications/climate-impacts-and-vulnerability-2012.

EEA, European Commission, and World Health Organization. 2008. *Impacts of Europe's Changing Climate: 2008 Indicator-Based Assessment: Joint EEA-JRC-WHO Report*. EEA Report, no. 4/2008. Copenhagen : Luxembourg: European Environment Agency ; Office for Official Publications of the European Communites [distributor].

Eliasson, I., B. Offerle, C.S.B. Grimmond, and S. Lindqvist. 2006. "Wind Fields and Turbulence Statistics in an Urban Street Canyon." *Atmospheric Environment* 40 (1): 1–16. doi:10.1016/j.atmosenv.2005.03.031.

ENVI-MET. 2014. "ENVI-Met. A Holistic Microclimate Modelling System." http://www.envi-met.info/hg2e/doku.php?id=root:start.

Esri. 2014. "ArcGIS Help 10.2 - FuzzyLinear (arcpy.sa)." http://resources.arcgis.com/en/help/main/10.2/index.html#//005m0000003s000000.

European Commission. 2014. "Adaptation Support Tool. Assessing Risks and Vulnerability to Climate Change." Accessed October 29. http://climate-adapt.eea.europa.eu/adaptation-support-tool/step-2-4.

Flynn, A., C. McGreevy, and E. C. Mulkerrin. 2005. "Why Do Older Patients Die in a Heatwave?" *QJM* 98 (3): 227–29. doi:10.1093/qjmed/hci025.

Friedrichs, Jürgen. 1990. *Methoden empirischer Sozialforschung*. 14. Aufl. Opladen: WestdtVerl.

Füssel, Hans-Martin, and Richard J. T. Klein. 2006. "Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking." *Climatic Change* 75 (3): 301–29. doi:10.1007/s10584-006-0329-3.

Gausemeier, Jürgen., Alexander. Fink, and Oliver. Schlake. 1995. *Szenario-Management: Planen und Führen mit Szenarien*. München; Wien: Hanser.

Greiving, Stefan. 2013. "Multi-Risk Assessment of Europe's Regions." *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*, 277–303.

Greiving, Stefan, and Mark Fleischhauer. 2012. "National Climate Change Adaptation Strategies of European States from a Spatial Planning and Development Perspective." *European Planning Studies* 20 (1): 27–48. doi:10.1080/09654313.2011.638493.

Grimmond, C. S. B., M. Roth, T. R. Oke, Y. C. Au, M. Best, R. Betts, G. Carmichael, et al. 2010. "Climate and More Sustainable Cities: Climate Information for Improved Planning and Management of Cities (Producers/Capabilities Perspective)." *Procedia Environmental Sciences* 1: 247–74. doi:10.1016/j.proenv.2010.09.016.

Hacker, A., and R. Zuckerstätter-Semela. 2014. *Tätigkeitsbericht SUM 2014*. www.stadt-umland.at/index.php?id=132.

———. 2015. "Stadt-Umland Management | SUM Gesamt." Accessed February 22. www.stadt-umland.at/index.php?id=83.

Hajat, Shakoor, and Tom Kosatky. 2010. "Heat-Related Mortality: A Review and Exploration of Heterogeneity." *Journal of Epidemiology and Community Health* 64 (9): 753–60. doi:10.1136/jech.2009.087999.

Harlan, Sharon L., Anthony J. Brazel, Lela Prashad, William L. Stefanov, and Larissa Larsen. 2006. "Neighborhood Microclimates and Vulnerability to Heat Stress." *Social Science & Medicine* 63 (11): 2847–63. doi:10.1016/j.socscimed.2006.07.030.

Herold. 2014. "ArcData HEROLD Firmendaten Österreich." http://www.wigeogis.com/de/neuigkeiten/Relaunch_ArcData_HEROLD_Firmendaten_Oesterreich.

Höppe, Peter. 1999. "The Physiological Equivalent Temperature–a Universal Index for the Biometeorological Assessment of the Thermal Environment." *International Journal of Biometeorology* 43 (2): 71–75.

HSE UK, Health and Safty Executive United Kingdom. 2013. "Heat Stress in the Workplace." HSE UK. www.hse.gov.uk/pubns/indg451.htm.

Huang, Cunrui, Adrian Gerard Barnett, Xiaoming Wang, Pavla Vaneckova, Gerard FitzGerald, and Shilu Tong. 2011. "Projecting Future Heat-Related Mortality under Climate Change Scenarios: A Systematic Review." *Environmental Health Perspectives* 119 (12): 1681–90.

Hutter, Hans-Peter, Hanns Moshammer, Peter Wallner, Barbara Leitner, and Michael Kundi. 2007. "Heatwaves in Vienna: Effects on Mortality." *Wiener Klinische Wochenschrift* 119 (7-8): 223–27. doi:10.1007/s00508-006-0742-7.

IPCC. 2001a. "Glossary of Terms Used in the IPCC Third Assessment Report." In *IPCC Third Assessment Report*, 365–88. Cambridge, UK ; New York: Cambridge University Press.

———. 2001b. *Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by James J. McCarthy. Cambridge, UK ; New York: Cambridge University Press.

———. 2001c. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, USA. http://www.ipcc.ch/ipccreports/tar/wg1/pdf/WG1_TAR-FRONT.PDF.

Jacob, Daniela, H. Göttel, S. Kotlarski, Ph Lorenz, and K. Sieck. 2008. "Klimaauswirkungen Und Anpassung in Deutschland–Phase 1: Erstellung Regionaler Klimaszenarien Für Deutschland. Abschlussbericht Zum UFOPLAN-Vorhaben 204 41 138." *Umweltbundesamt (ed.), Climate Change* 11 (08).

Kyselý, Jan. 2002. "Temporal Fluctuations in Heat Waves at Prague–Klementinum, the Czech Republic, from 1901–97, and Their Relationships to Atmospheric Circulation." *International Journal of Climatology* 22 (1): 33–50. doi:10.1002/joc.720.

Lebhart, Gustav, Stephan Marik-Lebeck, and Johannes Klotz. 2007. *Kleinräumige Bevölkerungsprognose Für Wien 2005 Bis 2035*. Stadtentwicklung Wien, Magistratsabt. 18, Stadtentwicklung und Stadtplanung.

Littig, Beate, and Erich Grießler. 2004. "Soziale Nachhaltigkeit." Bundeskammer für Arbeiter uAngestellte.

Lung, Tobias, Carlo Lavalle, Roland Hiederer, Alessandro Dosio, and Laurens M. Bouwer. 2013. "A Multi-Hazard Regional Level Impact Assessment for Europe Combining Indicators of Climatic and Non-Climatic Change." *Global Environmental Change* 23 (2): 522–36. doi:10.1016/j.gloenvcha.2012.11.009.

Magistrat der Stadt Wien. 2009. "Klimaschutzprogramm Der Stadt Wien. Fortschreibung 2010-2020."

Mahdavi, Ardeshir, Kristina Kiesel, and Milena Vuckovic. 2014. "Empirical and Computational Assessment of the Urban Heat Island Phenomenon and Related Mitigation Measures." *Geographia Polonica* 87 (4): 505–16. doi:10.7163/GPol.2014.34.

Max-Planck-Institut für Meteorologie. 2014. "ECHAM5." Accessed November 6. http://www.mpimet.mpg.de/en/wissenschaft/modelle/echam/echam5.html.

Morris, C. J. G., I. Simmonds, and N. Plummer. 2001. "Quantification of the Influences of Wind and Cloud on the Nocturnal Urban Heat Island of a Large City." *Journal of Applied Meteorology* 40 (2): 169–82. doi:10.1175/1520-0450(2001)040<0169:QOTIOW>2.0.CO;2.

Muenz, Rainer. 2007. "Aging and Demographic Change in European Societies: Main Trends and Alternative Policy Options." *Social Protection, The World Bank. Discussion Paper*, no. 703.

Muthers, Stefan, Andreas Matzarakis, and Elisabeth Koch. 2010. "Summer Climate and Mortality in Vienna – a Human-Biometeorological Approach of Heat-Related Mortality during the Heat Waves in 2003." *Wiener Klinische Wochenschrift* 122 (17-18): 525–31. doi:10.1007/s00508-010-1424-z.

NÖ ROG (Niederösterreichisches Raumordnungsgesetz) 2014, LGBl. Nr. 3/2015.

ÖNORM B 8110-3, :2012 03 15. n.d. *Wärmeschutz Im Hochbau - Teil 3: Vermeidung Sommerlicher Überwärmung*.

Pelling, Mark. 2003. *The Vulnerability of Cities: Natural Disasters and Social Resilience*. Earthscan.

PGO, Planungsgemeinschaft Ost. 2002. *ZIELE UND AKTIVITÄTEN ZUR WIENERWALD-DEKLARATION 2002*. http://www.pgo.wien.at/pgo_d.html.

Rahmstorf, Stefan, and Hans Joachim Schellnhuber. 2012. *Der Klimawandel: Diagnose, Prognose, Therapie*. CH Beck.

Rannow, Sven, Wolfgang Loibl, Stefan Greiving, Dietwald Gruehn, and Burghard C. Meyer. 2010. "Potential Impacts of Climate Change in Germany—Identifying Regional Priorities for Adaptation Activities in Spatial Planning." *Landscape and Urban Planning*, Climate Change and Spatial Planning, 98 (3–4): 160–71. doi:10.1016/j.landurbplan.2010.08.017.

Richter, Daniela. 2010. "Mapping Vulnerability to Climate Change in Santiago de Chile." Vienna: Wien.

Salamanca, F., M. Georgescu, A. Mahalov, M. Moustaoui, and M. Wang. 2014. "Anthropogenic Heating of the Urban Environment due to Air Conditioning." *Journal of Geophysical Research: Atmospheres* 119 (10): 2013JD021225. doi:10.1002/2013JD021225.

Sampson, Natalie R., Carina J. Gronlund, Miatta A. Buxton, Linda Catalano, Jalonne L. White-Newsome, Kathryn C. Conlon, Marie S. O'Neill, Sabrina McCormick, and Edith A. Parker. 2013. "Staying Cool in a Changing Climate: Reaching Vulnerable Populations during Heat Events." *Global Environmental Change* 23 (2): 475–84. doi:10.1016/j.gloenvcha.2012.12.011.

Schmidt, J. Alexander, and Hannah Baltes. 2012. "Adapting Cities to Climate Change: Scenarios for Urban Neighbourhoods in the City of Essen." In *Resilient Cities 2*, 149–57. Springer.

Schuurman, Nadine, Myriam Berube, and Valorie A. Crooks. 2010. "Measuring Potential Spatial Access to Primary Health Care Physicians Using a Modified Gravity Model." *The Canadian Geographer/Le Géographe Canadien* 54 (1): 29–45.

Stadt Wien. 2011a. "Stadtplan Grundkarte." *Datenkatalog | Für Eine Offene Stadt*. https://open.wien.at.

———. 2011b. "Bezirksgrenzen." https://open.wien.at/site/datensatz/?id=2ee6b8bf-6292-413c-bb8b-bd22dbb2ad4b.

———. 2012a. "Realnutzungskartierung 2007/08." *Datenkatalog | Für Eine Offene Stadt*. https://open.wien.at.

———. 2012b. "Realnutzungskartierung 2001." *Datenkatalog | Für Eine Offene Stadt*. https://open.wien.at.

———. 2014a. "Krankenhäuser - Standorte." *Datenkatalog | Für Eine Offene Stadt*. https://open.wien.at.

———. 2014b. "Baumkataster." *Datenkatalog | Für Eine Offene Stadt*. https://open.wien.at.

———. 2014c. "Gebäude in Wien - Gebäudemerkmale." *Für Eine Offene Stadt*. https://open.wien.at/site/datensatz/.

Stadt Wien/MA 18. 2012. "Regionalisierte Bevölkerungsprognose 2005 - 2035." *Datenkatalog | Für Eine Offene Stadt*. https://open.wien.at.

———. 2015. "STEP 2025. Fachkonzept Grün- Und Freiraum."

Stadt Wien/MA 21. 2014. "„Hirschstettner Hauptallee" - Lokaler Grünplan Am Beispiel Der Stadtentwicklungsgebiete Berresgasse Und Pfalzgasse/ Am Heidjöchl."

Stafoggia, Massimo, Francesco Forastiere, Daniele Agostini, Annibale Biggeri, Luigi Bisanti, Ennio Cadum, Nicola Caranci, et al. 2006. "Vulnerability to Heat-Related Mortality: A Multicity, Population-Based, Case-Crossover Analysis." *Epidemiology* 17 (3): 315–23. doi:10.1097/01.ede.0000208477.36665.34.

STATISTIK AUSTRIA. 2001. "Volkszählung 2001." http://www.statistik.at.

———. 2013. “Bevölkerungsprognose 2013.” http://www.statistik.at/web_de/statistiken/bevoelkerung/demographische_prognosen/bevoelkerungsprognosen/.

———. 2014. “Statistik Des Bevölkerungsstandes.” www.statistik.at/web_de/statistiken/bevoelkerung/bevoelkerungsstand_und_veraenderung/bevoelkerung_im_jahresdurchschnitt/index.html.

Stiles, R., B. Gasienica-Wawrytko, K. Hagen, H. Trimmel, W. Loibl, M. Köstl, T. Tötzer, S. Pauleit, A. Schirmann, and W. Feilmayr. 2014. *Urban Fabric Types and Microclimate Response – Assessment and Design Improvement. Final Report.* TU Wien. http://urbanfabric.tuwien.ac.at/index.php/de/ergebnisse-endbericht.

Stock, Manfred. 2013. “Der Klimawandel: Global Und Regional in Europa Und Deutschland.” In *Raumentwicklung Im Klimawandel. Herausforderungen Für Die Räumliche Planung*. Hannover: Jörn Birkmann, Maike Vollmer, Jochen Schanze.

Taha, Haider. 1997. “Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat.” *Energy and Buildings* 25 (2): 99–103.

Umweltbundesamt, and European Environmental Agency EEA. 2000. “CORINE Land Cover.” http://www.umweltbundesamt.at/umweltsituation/umweltinfo/opendata/oed_landbedeckung.

United Nations, Department of Economic and Social Affairs, Population Division. 2013. *World Population Prospects: The 2012 Revision, DVD Edition*. http://esa.un.org/wpp/Excel-Data/population.htm.

Vienna City Administration. 2005. “STEP 05 - Stadtentwicklungsplan Wien 2005.” Municipal Department 18 (MA 18) - Urban Development and Planning.

———. 2014. “STEP 2025 - Stadtentwicklungsplan Wien.” Municipal Department 18 (MA 18) - Urban Development and Planning.

White-Newsome, Jalonne L., Brisa N. Sánchez, Olivier Jolliet, Zhenzhen Zhang, Edith A. Parker, J. Timothy Dvonch, and Marie S. O’Neill. 2012. “Climate Change and Health: Indoor Heat Exposure in Vulnerable Populations.” *Environmental Research* 112 (January): 20–27. doi:10.1016/j.envres.2011.10.008.

WHO, World Health Organisation. 2009. “Improving Public Health Responses to Extreme Weather/heat-Waves. Summary for Policy-Makers. EuroHEAT.” http://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/publications/2009/improving-public-health-responses-to-extreme-weatherheat-waves.-summary-for-policy-makers.-euroheat.

Wilms, Falko E. P. 2006. *Szenariotechnik: vom Umgang mit der Zukunft*. Bern; Stuttgart; Wien: Haupt.

ZAMG. 2002. “Klimadaten von Österreich 1971 - 2000.” http://www.zamg.ac.at/fix/klima/oe71-00/klima2000/klimadaten_oesterreich_1971_frame1.htm.

———. 2013a. “Jahrbuch.” http://www.zamg.ac.at/cms/de/klima/klimauebersichten/jahrbuch.

———. 2013b. “Stadtklima Zukunft.” http://www.zamg.ac.at/cms/de/klima/informationsportal-klimawandel/daten-download/stadtklima-zukunft.

Žuvela-Aloise, M., R. Koch, C. Matulla, and J. Nemec. 2013. “FOCUS-I Adaption and Mitigation of the Climate Change Impact on Urban Heat Stress Based on Model Runs Derived with an Urban Climate Model, ACRP Project Nr. B060373.”