Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Project Data

Allgemeines zum Projekt	
Kurztitel:	Urban Climate Change Adaptation for Austrian Cities
Langtitel:	Urban Climate Change Adaptation for Austrian Cities: Urban Heat Islands
Zitiervorschlag:	ADAPT-UHI
Programm inkl. Jahr:	Austrian Climate Research Programme 2017
Dauer:	19.03.2018 bis 18.03.2020
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	International Institute for Applied Systems Analysis (IIASA), Niederösterreich Umweltbundesamt GmbH (UBA), Wien Zentralanstalt für Meteorologie und Geodynamik (ZAMG), Wien International Project Management Agency Klagenfurt on Lake Wörthersee GmbH (IPAK), Kärnten
Schlagwörter:	Climate change adaptation, climate change mitigation, Urban Heat Island, urban climate modelling, risk, cost-benefit analysis
Projektgesamtkosten:	249.936 €
Fördersumme:	249.936 €

Allgemeines zum Projekt	
Klimafonds-Nr:	KR17AC0K13693
Erstellt am:	19.06.2020

B) Project Overview

1 Kurzfassung

Die Erhöhung von Temperaturen in städtischen Gebieten aufgrund einer großen Anzahl undurchlässiger Oberflächen, mangelnder Vegetation und konzentrierter städtischer Strukturen werden als Urban Heat Island (UHI)-Effekt bezeichnet. Dieser kann sich in Kombination mit Hitzewellen negativ auf die menschliche Gesundheit und das Wohlbefinden auswirken. Um den UHI-Effekt zu berücksichtigen und urbane Strategien zur Anpassung an den Klimawandel zu entwickeln, benötigen Stadtplaner Unterstützung und zusätzliche Informationen. Großstädte wie Wien befassen sich bereits umfangreich mit dem Thema, deshalb war es das übergeordnete Ziel des ADAPT-UHI-Projekts vor allem Stadtplaner in kleineren und mittelgroßen Städten in Österreich zu unterstützen.

Drei Pilotstädte nahmen an dem Projekt teil: Mödling, Klagenfurt am Wörthersee und Salzburg. Mit jeder Stadt wurden Workshops abgehalten, um ihre Bedarfe in Bezug auf die Anpassung an den Klimawandel zu verstehen und stadtspezifische Daten für die Eingabe in ein städtisches Klimamodell zu erhalten. Das Modell wurde verwendet, um verschiedene Szenarien zu entwickeln und um die Auswirkungen verschiedener Anpassungsmaßnahmen zu verstehen. Die getesteten Strategien umfassten sogenannte „weiße Maßnahmen" (solche, die die „Albedo", also das Rückstrahlvermögen von Dächern, Wänden und Straßenoberflächen erhöhen, als White City Szenario bezeichnet), „grüne Maßnahmen" (solche, die die Umgebungsluft abkühlen durch Hinzufügen von Vegetation, wie z. B. Gründächer, Bäume, Grünflächen, usw., zusammen als Green City Szenario bezeichnet) und die Kombination beider Maßnahmen (kombiniertes Szenario). Anschließend wurde eine Kosten-Nutzen-Analyse der Szenarien durchgeführt. Abschließend wurden in jeder Stadt Workshops abgehalten, um die Ergebnisse zu präsentieren, die Anpassungsszenarien gegebenenfalls zu modifizieren und um die Empfehlungen auf der Grundlage der Modellierungsergebnisse und Best Practices zu diskutieren.

Das Projekt entwickelte noch weitere Stadtplanungstools zur besseren urbanen Anpassung an den Klimawandel. Erstens wurde ein UHI-Risikoindex für Österreich mit einer Auflösung von 100m erstellt, der auf einer Kombination aus meteorologischen Indikatoren, Landbedeckungs- und Siedlungsdaten und demografischen Indikatoren, inklusive der am stärksten gefährdeten Bevölkerungsteile basiert. Zweitens wurden „Urban Quality Climate Maps" für jede Pilotstadt erstellt. Sie liefern Informationen zu jenen Gebieten der Stadt, die die größte Verdunstungskühlung durch Vegetation und Wasser aufweisen und in denen Gebäude und Vegetation beschattet sind, was ebenfalls zur Kühlung beiträgt. Beide Tools können von Stadtplanern verwendet werden, um Planungsmaßnahmen in der Zukunft klimagerecht zu entwickeln und zu implementieren.

Die Ergebnisse des Projekts, sind auf der Projektwebsite (https://www.adapt-uhi.org) verfügbar und umfassen die Anpassungsszenarien für einzelne weiße, grüne und kombinierte Maßnahmen für jede der Pilotstädte, die Kosten-Nutzen-Analyse, allgemeine und stadtspezifische Empfehlungen für Anpassungsmaßnahmen, den UHI-Risikoindex für Österreich und die „Urban Quality Climate Maps".

Die folgenden Ergebnisse und Schlussfolgerungen wurden aus dem Projekt gezogen:

- Für das aktuelle Klima (1971-2000) wurde der UHI-Risikoindex für jede Stadt als jährliche (räumlich gemittelt) durchschnittliche Anzahl von Sommertagen (ST, $\text{Temp}_{\text{max}} \geq 25°\text{C}$) quantifiziert. Er betrug 54,5 ST für Mödling, 62,7 ST für Klagenfurt und 43,9 ST für Salzburg.
- Mit zukünftigen Klimaprojektionen wird die Anzahl der ST in den Pilotstädten, für den Zeitraum 2071-2100 im Vergleich zum Zeitraum 1971-2000, von 28-55% unter RCP4.5 (Szenario, in dem die Emissionen bis 2040 steigen) und von 30-112% unter RCP8.5 (Worst case-Szenario) steigen.
- Das kombinierte Anpassungsszenario ergab die größte Reduzierung des UHI-Risikos (gemessen für heiße Tage, HT – $\text{Temp}_{\text{max}} \geq 30°\text{C}$) im Vergleich zu den Szenarien Green City, White City oder einzelnen Anpassungen.
- Von den White and Green City-Szenarien hat die White City in allen drei Städten die größten HD-Reduzierungen erzielt.
- Die effektivste individuelle Anpassungsmaßnahme war die Verdoppelung der Dachalbedo in allen drei Städten.
- Das kombinierte Szenario in Mödling umfasste alle benachbarten Bezirke von Mödling unter einem zukünftigen Klimaszenario (2021-2050) und RCP8.5. Es zeigt, dass die Anzahl von HT in Mödling sowie in allen Nachbarbezirken stärker verringert wird, wenn alle Bezirke die kombinierten Anpassungsmaßnahmen umsetzen, als wenn nur Mödling allein die Maßnahmen umsetzen würde. Ein ähnlicher Effekt wurde für Salzburgs Nachbarstadt Freilassing in Deutschland gezeigt. Dies weist darauf hin, dass auch in der Stadtplanung eine regionale und transnationale Zusammenarbeit von Vorteil wäre.
- Die Stadt Klagenfurt bleibt bis 2050 auf etwa dem gleichen HT-Niveau (von 1981 bis 2010), wenn die kombinierten Anpassungsmaßnahmen umgesetzt werden. Die derzeitig vorhandenen Pläne für zukünftige Bebauung werden die Anzahl der HT erhöhen. Nachhaltige Bauweisen werden jedoch helfen die zusätzliche städtische Wärmebelastung zu verringern.
- Die Stadt Salzburg bleibt bis 2050 auf etwa dem gleichen HT-Niveau (von 1981 bis 2010), wenn die kombinierten Anpassungsmaßnahmen umgesetzt werden.
- Die Kosten-Nutzen-Analyse ergab, dass in fast allen Szenarien der Nutzen die Kosten überwiegt.
- Der UHI-Risikoindex zeigt, dass 80%, 60% und 74% von Mödling, Klagenfurt und Salzburg in die Kategorien mit hohem bis sehr hohem Risiko für den UHI-Effekt und Hitzeeinflüsse fallen.

Zusammenfassend hat das ADAPT-UHI-Projekt eine Reihe von Empfehlungen für die Stadtplanung in Bezug auf die Anpassung an den Klimawandel für drei kleinere bis mittelgroße Städte in Österreich erstellt. Die Empfehlungen basieren auf der Modellierung des Stadtklimas unter bestimmten Anpassungsszenarien und aktuellen Best Practices. Es wurden andere städteplanerische Instrumente entwickelt (UHI-Risikoindex und „Urban Climate Quality Maps“), die die Stadtplanung für die zukünftige Klimaanpassung anleiten können.

2 Executive Summary

Increased temperatures in urban areas due to high amounts of impervious surfaces, a lack of vegetation and concentrated urban structures is called the Urban Heat Island (UHI) effect, which in combination with heat waves, can negatively impact human health and well-being. To address the UHI effect and extreme heat in cities, urban planners need support in developing strategies for climate change adaptation. Although considerable work has been undertaken in large cities like Vienna, urban planners in small- to medium-sized cities in Austria need support, which was the overall aim of the ADAPT-UHI project.

Three pilot cities participated in the project: Mödling, Klagenfurt am Wörthersee (hereafter Klagenfurt) and Salzburg. Initial workshops were held with each city to understand their needs in terms of climate change adaptation and to obtain city-specific data for input to an urban climate model. This was used to run various scenarios to determine the effects of implementing different adaptation measures including white measures (i.e., those that increase the reflectivity of roofs, walls and road surfaces – collectively referred to as the White City), green measures (i.e., those that increase the cooling of the ambient air temperature by adding vegetation such as green roofs, increasing the number of trees and greenspace, etc. – collectively referred to as the Green City) and the combination of both sets of measures (Combined scenario). A cost-benefit analysis of these scenarios was then undertaken, considering heat-reduction related benefits as well as ecosystem service benefits. Subsequent workshops were held with each city to present the results, tailor the adaptation scenarios and to present recommendations based on the modelling results and best practices.

The project also developed other tools to guide urban planning for climate change adaptation. The first was a UHI Risk Index for Austria, produced at a 100 m resolution, which is based on a combination of meteorological indicators, land cover, settlement data and demographic indicators, including the population most at risk. The second was the development of Urban Climate Quality Maps for each pilot city, which provide information on the areas of the city that have the largest evaporative cooling from vegetation and water and where there is shading from buildings and vegetation, which also contributes to cooling. Both tools can be used by urban planners to guide the implementation of planning interventions in the future.

The results of the project, available from the project website (https://www.adapt-uhi.org), include the adaptation scenarios for individual white, green and combined measures for each of the pilot cities, the cost-benefit analysis, general and city-specific recommendations for adaptation measures that should be implemented in urban areas, the UHI Risk Index for Austria, and the Urban Climate Quality Maps.

The following results and conclusions were derived from the project:

- For the recent climate (1971-2000), the UHI effect was quantified for each city, which was based on the annual spatially-averaged number of summer days (SD, T≥25°C), which was 54.5 SD for Mödling, 62.7 SD for Klagenfurt and 43.9 SD for Salzburg calculated over the model domain.
- With future climate projections, the number of SD will increase from 28-55% under RCP4.5 (scenario in which emissions will decrease by 2040) and 30-112% under RCP8.5 (worst case scenario) in the pilot cities for the time period 2071-2100 in comparison to 1971-2000.
- The Combined adaptation scenario provided the largest reductions in the number of hot days (HD, T_{max}≥30°C) compared to the Green City, White City or individual adaptation scenarios.
- Of the White and Green City scenarios, the White City produced the largest average reductions in HD in all three cities.
- The most effective individual adaptation measure was doubling the roof albedo in all three cities.
- The Combined scenario that included all neighboring districts of Mödling under a future climate (2021-2050) and RCP8.5 showed that if all districts implement the Combined adaptation measures, then the reductions in the number of HD would be greater in Mödling as well as all neighboring districts compared to the situation in which only Mödling implemented the measures. A similar effect was demonstrated for Salzburg's neighboring town of Freilassing in Germany. This indicates that regional/transnational cooperation would be beneficial in urban planning.
- The city of Klagenfurt remains at around the same level of HD in 1981-2010 until 2050 if the combined adaptation measures are implemented. Future building plans will increase the number of HD, but the sustainable construction methods to be used will mitigate the urban heat load.
- The city of Salzburg will remain at around the same level of HD in 1981-2010 until 2050 if the combined adaptation measures are implemented.
- The cost-benefit analysis showed that for almost all scenarios, the benefits outweigh the costs.
- The UHI Risk Index showed that 80%, 60% and 74% of Mödling, Klagenfurt and Salzburg fall within the high to very high-risk categories for UHI and heat impacts.

In summary, the ADAPT-UHI project produced a set of recommendations to guide urban planning in relation to climate change adaptation in three small- to medium-sized cities in Austria.

3 Background and Objectives

Cities are particularly vulnerable to increasing temperatures from climate change because of a phenomenon known as the Urban Heat Island (UHI) effect (Oke 1967). The increased temperatures measured in urban areas are the result of higher amounts of impervious surfaces, lack of vegetation and concentrated urban structures. The UHI, in combination with heat waves, affects human health and well-being, and heat waves in urban areas have contributed to loss of life. For example, during the heat wave in 2003, more than 30,000 people in Europe are estimated to have perished (UNEP 2004). By 2071 to 2100, it is predicted that 152,000 people will perish in Europe annually (Forzieri et al. 2017). Moreover, a recent study has found that if global temperatures increase by 4°C, heatwaves of 55°C may regularly impact many parts of the world, including Europe (Russo et al. 2017). There are other negative effects of urban climate related to increasing air pollution and in the general reduction of thermal comfort (Harlan and Ruddell 2011). The Intergovernmental Panel on Climate Change (IPCC) future climate scenarios indicate higher frequency and duration of heat waves in the coming decades, which will further increase health risks (Revi et al. 2014).

Large cities like Vienna have already investigated the UHI effect and developed possible climate change mitigation and adaptation strategies, e.g., through the previously funded ACRP project FOCUS-I (ZAMG 2013) and the Central Europe project UHI (Preiss and Härtel 2015). However, there has been little work undertaken to support urban planners in small- to medium-sized cities in Austria at the city scale. For example, by using an urban climate model like MUKLIMO, it is possible for cities to not only estimate effects on individual buildings or grid squares, but they can also obtain an impression of the effects of potential adaptation measures implemented at the city scale.

The ADAPT-UHI project was designed to fill this gap. Hence, the overall aim of the ADAPT-UHI project was to support urban planners in small- to medium-sized cities in Austria in decision making through the provision of climate services to guide the development of strategies and action plans for climate change adaptation and mitigation. To achieve this overall aim, the ADAPT-UHI project had four main objectives as outlined below.

Objective 1: To generate climate indicators and a UHI Risk Index for Austria

The idea behind this objective was to provide a UHI Risk Index map at a 1x1 km^2 resolution for all of Austria, similar to what had been produced previously in Germany. The UHI Risk Index would use climate indicators related to heat load and thermal comfort as one input as well as the population at risk. However, the complete methodology was developed during the project. This product is targeted at urban planners across Austria to determine areas of highest risk for potential planning interventions.

Objective 2: To generate multiple scenarios of future climate for three pilot cities in Austria

Three small- to medium-sized pilot cities were recruited during the proposal submission phase: Mödling, Klagenfurt am Wörthersee (hereafter Klagenfurt) and Salzburg. An urban climate model was then used to generate a range of adaptation scenarios for each city, e.g., what would be the effect of adding green roofs or more greenspace to the city in terms of mitigating the UHI, now and in the future?

Objective 3: To present a range of possible solutions to aid in decision making

This objective was aimed at turning the project results into recommendations for adaptation measures with indicative costs, to aid in the development of strategies for climate adaptation and mitigation. These recommendations could then be incorporated into smart city plans and future developments.

Objective 4: To contribute to capacity building in Austria in the area of climate smart services as part of a larger provision of services related to smart cities

By working with three pilot cities in ADAPT-UHI, the idea was to build Austrian capacity in this area, and to serve as a model for expansion to other cities in the need of such services. Moreover, climate services are only one information source needed by urban planners and hence, ADAPT-UHI would contribute to a broader vision in the future development of smart cities.

4 Project Contents and Results

The overall aim of the ADAPT-UHI project was to provide support to small- to medium-sized cities in climate change adaptation and mitigation. The main tool to achieve this was through urban climate modelling, which allows adaptation scenarios to be simulated at a high spatial resolution. These simulations were then coupled with a cost-benefit analysis to examine their feasibility. The results were then translated into a set of recommendations to guide climate change adaptation in future smart city plans and climate change strategies. Additional urban planning tools for climate change adaptation and mitigation were developed, including the UHI Risk Index, which combines several indicators to highlight those areas at high risk of the UHI at a 100x100 m^2 resolution, and Urban Climate Quality Maps, which indicate areas of the city that are cooled through vegetation and shading during different periods of prolonged heating.

To achieve the project aim, the work plan was organized into five work packages (WPs) as outlined below.

WP1: Project Management

This work package handled all the administrative and financial tasks related to the project, in particular, the coordination of activities and tasks across all work packages to achieve the overall objectives of the project. This WP also ensured that there was effective communication and collaboration between the partners and that the project milestones were achieved in a timely manner.

WP2: User Requirements and Data Needs for the Pilot Cities in Austria

In this work package, initial workshops were set up to elicit the user requirements of each pilot city (Mödling, Klagenfurt and Salzburg) and to outline the city-specific data needed for the urban climate model. Working with each city, the data were then assembled and stored in a secure location.

A second task in this WP was to develop city greening quality maps for climate change adaptation for all pilot cities for use as urban planning tools. During the project, these were renamed to Urban Climate Quality Maps and included both green and blue areas.

WP3: Urban Climate Modelling and Generation of Climate Indicators

This work package had two main tasks. The first was to set up the detailed, high resolution urban climate model (using MUKLIMO_3) for each pilot city using input data specific to each city (i.e., land use, building data, elevation, soil sealing and vegetation from local, national (e.g., the LISA data set) and EU data sources (e.g., the Copernicus land monitoring service), and more. Once the model parameters were set, the urban climate model was used to simulate the current climate at a horizontal, spatial resolution of 20x20 m^2 for Mödling and 100x100 m^2 for

Klagenfurt and Salzburg. The model results were then validated using long term data records from meteorological stations in or nearby the pilot cities.

The second task was to develop a methodology for estimating a UHI risk indicator for all built-up areas in Austria based on a set of climate indicators and other relevant input data. The indicator was then checked for plausibility.

WP4: Future Climate and Urban Planning Scenarios for the Pilot Cities

This work package involved using the validated urban climate model to run a set of climate adaptation scenarios for each pilot city. These included the simulation of white measures such as increasing the reflectivity or albedo of roofs, walls and street surfaces (referred to collectively as the White City), and green measures such as increasing the number of green roofs, trees and vegetated surfaces (referred to collectively as the Green City). A Combined scenario of the White and Green City was also simulated.

These adaptation scenarios were then discussed during workshops to further refine these scenarios based on future buildings developments or other proposed changes in land use. These results were then translated into a set of general and city-specific recommendations for implementation of adaptation measures that can be used for smart city planning and climate change strategies. A cost-benefit analysis was undertaken for the White City, Green City and Combined scenarios, which included a temperature-mortality analysis, thereby bringing health risks into the model.

WP5: Decision Support and Dissemination

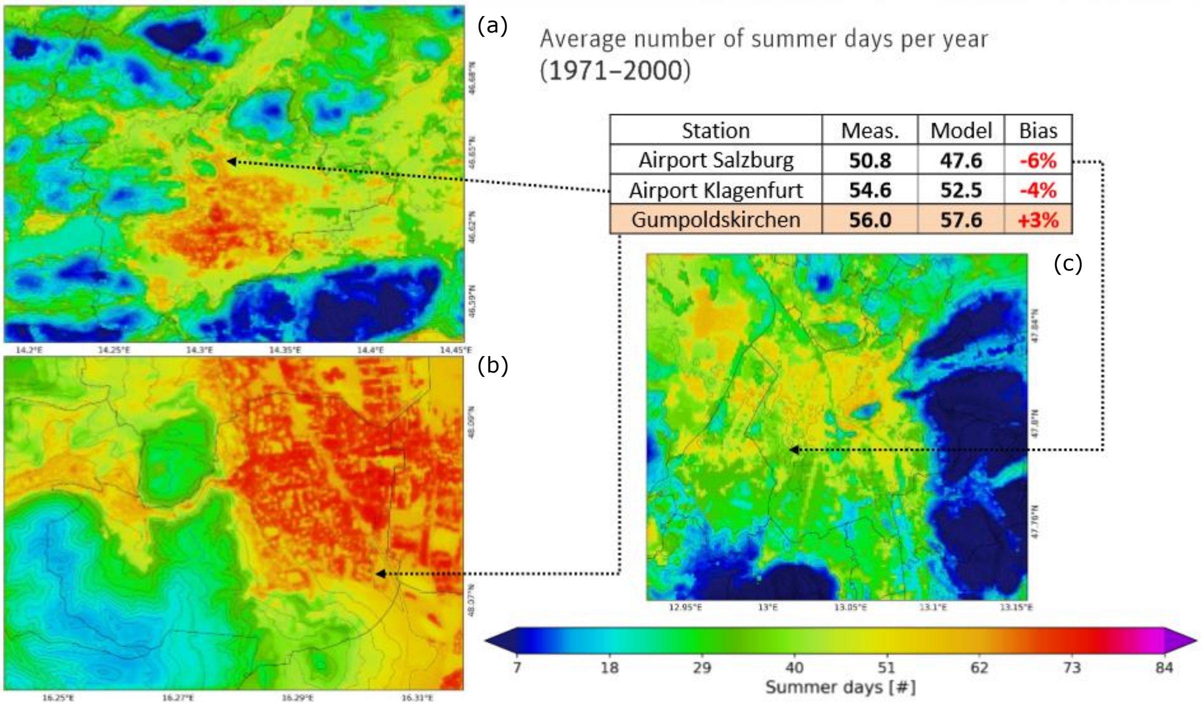
This work package had two main tasks. The first was the development of a visualization tool for the adaptation scenarios and UHI Risk Index while the second was the dissemination of project results through different channels, i.e., the project website, conference and workshop presentations, scientific papers, factsheets and brochures containing project outputs in a visual and appealing manner, and a final workshop involving the pilot cities and relevant stakeholders.

Project Results

The project results are organized into six major categories of activities as outlined below.

1 Urban Climate Modelling – Validation and Future Climate Projections

The urban climate model was set up for each pilot city and initial simulations were generated for the recent climate, which covers the periods 1971-2000 and 1981-2010. These results were then validated using data from a weather station in the pilot city or the closest weather station available. Figure 1 shows the measurements and the model results for the 1971-2000 time period. If the bias is in the range of ±10%, the model is considered to perform well. Figure 1 shows that the bias is well within this range for all three cities. A similar validation exercise was undertaken for the time period 1981-2010; the bias was less than 10% for both summer and hot days, or if slightly outside this range, an explanation was sought, e.g., changes in the location of the weather station or changes in land use. Hence the urban climate model was validated for the three pilot cities.



Station	Meas.	Model	Bias
Airport Salzburg	**50.8**	**47.6**	**-6%**
Airport Klagenfurt	**54.6**	**52.5**	**-4%**
Gumpoldskirchen	**56.0**	**57.6**	**+3%**

Figure 1: Simulation of the average annual number of summer days for 1971-2000 for (a) Klagenfurt (b) Mödling and (c) Salzburg validated using meteorological station data

After model validation, future climate projections, downscaled from an ensemble of Regional Climate Models and made available through the EURO-CORDEX project, were simulated with the urban climate model for the three pilot cities for two Representative Concentration Pathways, RCP4.5 (decreasing emissions after 2040 – shown in Figure 2) and RCP8.5 (worst case – shown in Figure 3). They provide two contrasting pathways to illustrate the increase in the average number of summer days over two future time periods: 2021-2050 and 2071-2100.

Looking at the average annual summer days across the time periods in the future across all three cities as shown in Figures 2 and 3, there is an increase of around 16 summer days (31%) on average from the recent past to 2021-2050 for RCP4.5, and around 24 summer days (45%) on average for 2071-2100. For RCP8.5, the average increase is around 17 days (32%) for 2021-2050 and 48 days (90%) for 2071-2100. Although there is clearly uncertainty in these climate projections, these simulations provided the pilot cities with an approximate size of the urban heat load now and in the future.

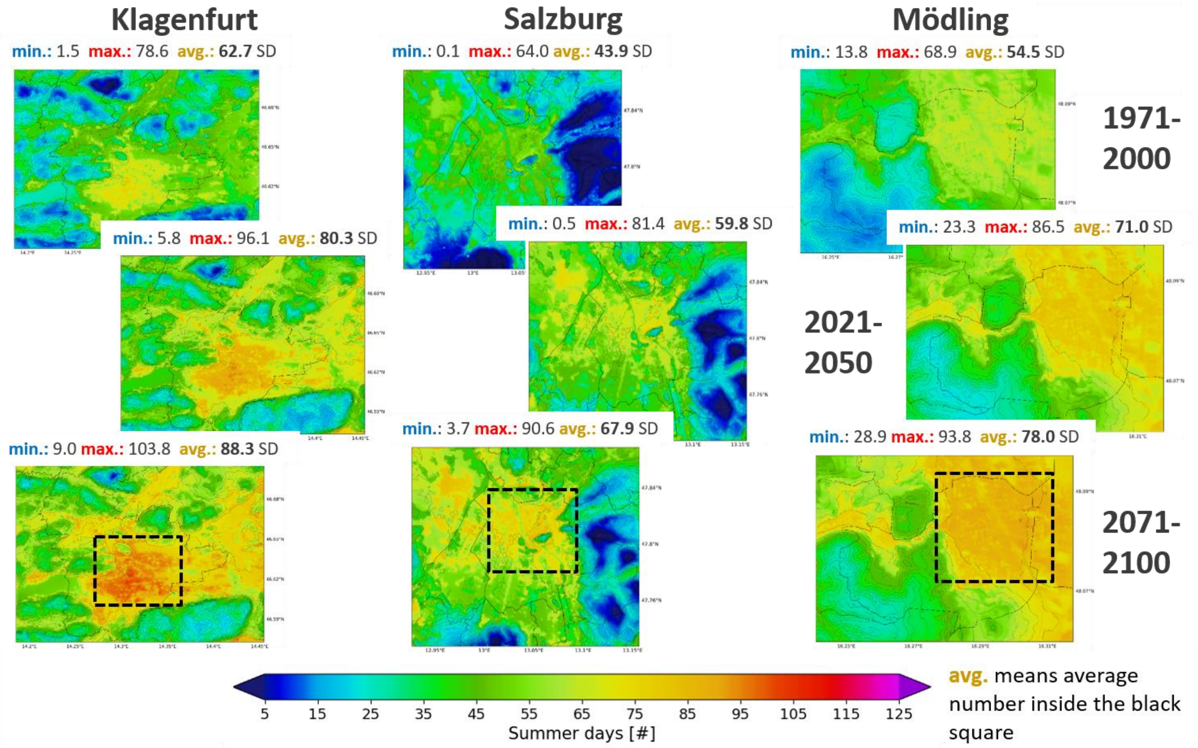


Figure 2: Past and future scenarios of mean number of summer days for RCP4.5

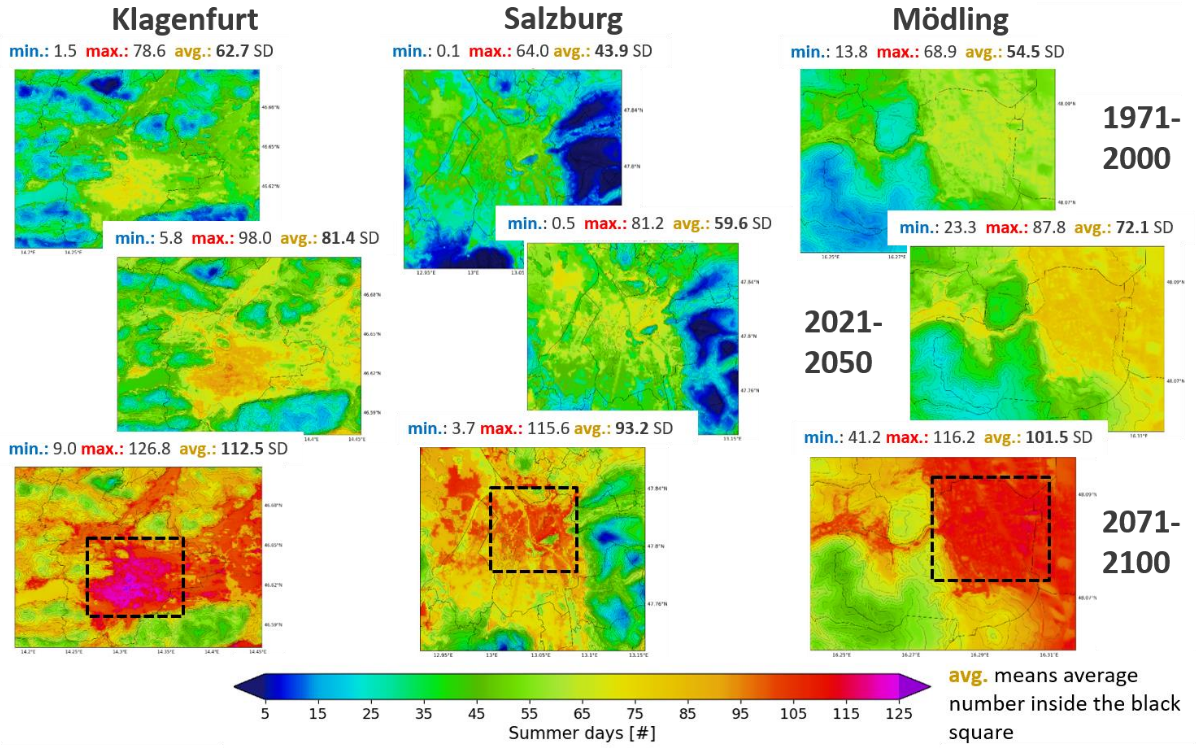


Figure 3: Past and future scenarios of mean number of summer days for RCP8.5

2 Urban Climate Modelling – Adaptation Scenarios

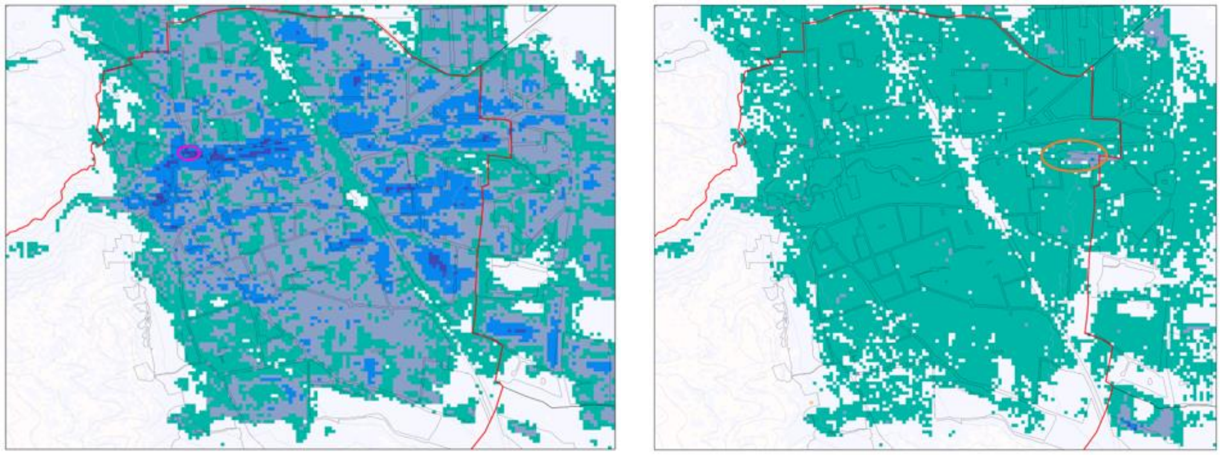
From the urban climate model results, the average number of hot days (HD, $T_{max} \geq 30°C$) for the period 1981-2010 is 15.5, 12.5 and 4.9 for Mödling, Klagenfurt and Salzburg, respectively. Within the cities, these range from 3, 2 and 0.3 HD for green areas to 24, 21 and 12.4 HD for the city centre of Mödling, Klagenfurt and Salzburg, respectively. The effects of different adaptation measures in reducing the heat load were evaluated by comparing the values of the HD with and without the adaptation measures implemented in the model; results are shown in Table 1.

Table 1: Average and maximum reduction in the number of hot days (HD, $T_{max} \geq 30°C$) for different adaptation scenarios in each pilot city as percentage and absolute value in HD

Adaptation Scenario	**Mödling**		**Klagenfurt**		**Salzburg**	
	Average Reduction in HD	**Largest Reduction in HD**	**Average Reduction in HD**	**Largest Reduction in HD**	**Average Reduction in HD**	**Largest Reduction in HD**
Double roof albedo	5.8% (1.0)	10.0% (2.2)	11.0% (1.4)	20.7% (4.0)	28.5% (1.4)	32.2% (3.8)
Double wall albedo	3.1% (0.5)	7.1% (1.6)	4.2% (0.5)	10.0% (2.0)	17.8% (0.9)	24.1% (2.7)
Double street albedo	3.8% (0.7)	9.9% (2.3)	9.1% (1.1)	17.1% (3.3)	16.2% (0.8)	25.5% (2.7)
White City (above three scenarios combined)	**13.2% (2.3)**	**20.3% (4.5)**	**25.2% (3.1)**	**37.8% (7.3)**	**38.2% (1.8)**	**47.5% (5.6)**
Decrease sealed areas	2.0% (0.3)	5.2% (1.2)	5.8% (0.7)	12.2% (2.3)	16.8% (0.8)	20.0% (2.2)
Increase green roofs by 50%	1.9% (0.3)	7.3% (1.0)	5.3% (0.7)	17.1% (2.5)	22.1% (1.1)	27.9% (3.1)
Increase the number of trees by 50%	2.1% (0.4)	21.7% (3.8)	2.3% (0.3)	20.2% (1.7)	15.3% (0.7)	29.7% (1.9)
Decrease unvegetated, pervious areas	2.4% (0.4)	15.3% (1.8)	4.2% (0.5)	12.2% (2.2)	14.4% (0.7)	26.5% (1.8)
Green City (above four scenarios combined)	**7.8% (1.4)**	**25.1% (4.4)**	**15.8% (2.0)**	**26.6% (4.7)**	**33.1% (1.6)**	**33.9% (4.0)**
Combined Scenario (White+Green)	**20.0% (3.5)**	**34.4% (6.3)**	**36.0% (4.5)**	**44.0% (9.2)**	**55.2% (2.7)**	**70.1% (7.5)**

The results in Table 1 show that the Combined scenario produces the largest overall and maximum reductions in HD in all three cities. Considering only the White and Green City scenarios, the White City produces larger average reductions than the Green City scenario in all three cities although the largest reduction in HD in Mödling is in the Green City scenario. Considering individual measures, doubling the roof albedo has the largest reductions in all three cities. This is followed by doubling the street albedo in Mödling and Klagenfurt and increasing green roofs in Salzburg by 50%.

In addition to the average and maximum reductions in HD for each adaptation scenario for each city, the spatial distribution of reductions in the number of HD was also provided. An example for Mödling is shown in Figure 4 for the White City, Green City and Combined scenarios. This confirms that there are larger reductions across the city for the White City scenario compared to the Green City while the Combined scenario shows the largest reductions overall. Figure 4a shows two locations for reference: (i) the city centre in Freiheitplatz in the red ellipse, which would have 17.5 HD under a White City scenario compared to 22 without adaptation measures, and Hyrtl Park in the orange ellipse (Figure 4b), which would have 8.8 HD under a Green City scenario instead of 11.9 HD. These would be further reduced to 16.2 HD for the city center and 7.8 HD for Hyrtl Park under a Combined scenario.



(a) (c) (b)

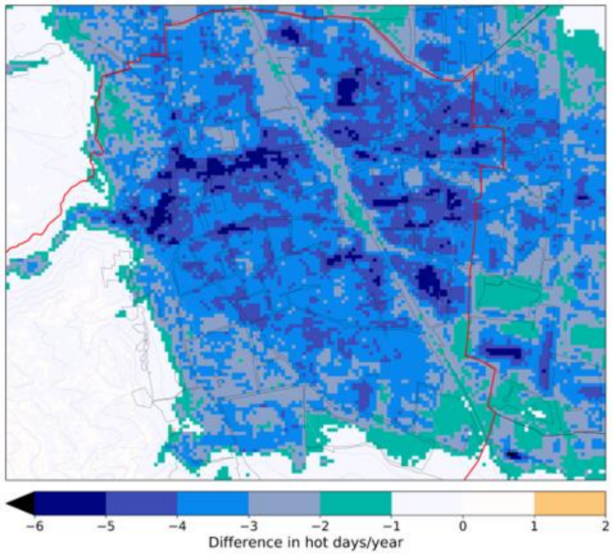


Figure 4: The reduction in the number of hot days simulated by the urban climate model for the (a) White City (b) Green City and (c) Combined scenarios for Mödling. The red ellipse in (a) shows Freiheitplatz in the city centre while the orange ellipse in (b) is Hyrtl Park.

Figure 5 shows the same scenarios for Klagenfurt, with the greatest reductions in the number of HD in the Combined scenario. Two points of reference are marked in the figure: Neuer Platz in the city centre as a red circle (Figure 5a) and Südpark Center as an orange circle (Figure 5b). Under a White City scenario, Neuer Platz would have 12 HD instead of 16.1 HD while Südpark Center would have 11.2 HD instead of 14.3 HD under a Green City scenario. These would be further reduced to 10.8 HD in Neuer Platz and 8.8 HD in Südpark Center in the Combined scenario. A fuller analysis of the results in Klagenfurt can be found in Oswald et al. (2020), available as an open access paper.

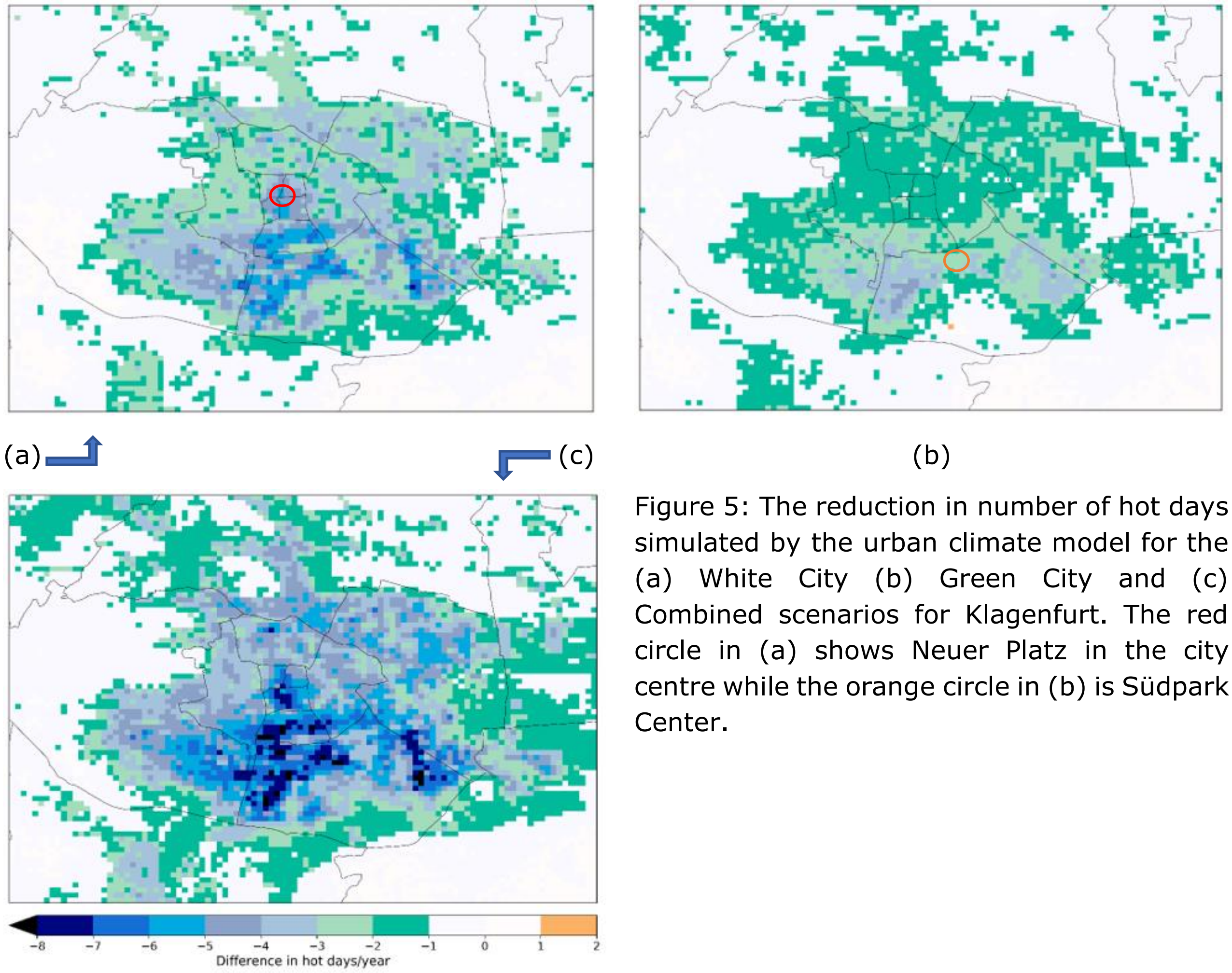


Figure 5: The reduction in number of hot days simulated by the urban climate model for the (a) White City (b) Green City and (c) Combined scenarios for Klagenfurt. The red circle in (a) shows Neuer Platz in the city centre while the orange circle in (b) is Südpark Center.

Finally, the results from Salzburg are shown in Figure 6. Once again, the Combined scenario shows the highest reductions in HD across the city. A city centre reference point is shown as a red circle (Getreidegasse). Under a White City scenario, Getreidegasse would have 4.9 HD instead of 10 HD. A second reference point is shown as an orange circle, which is the greener Volksgarten. Under a Green City scenario, Volksgarten would have 4.4 HD instead of 7.2 HD. These would be further reduced to 4.0 HD in Getreidegasse and 2.6 HD in Volksgarten in the Combined scenario.

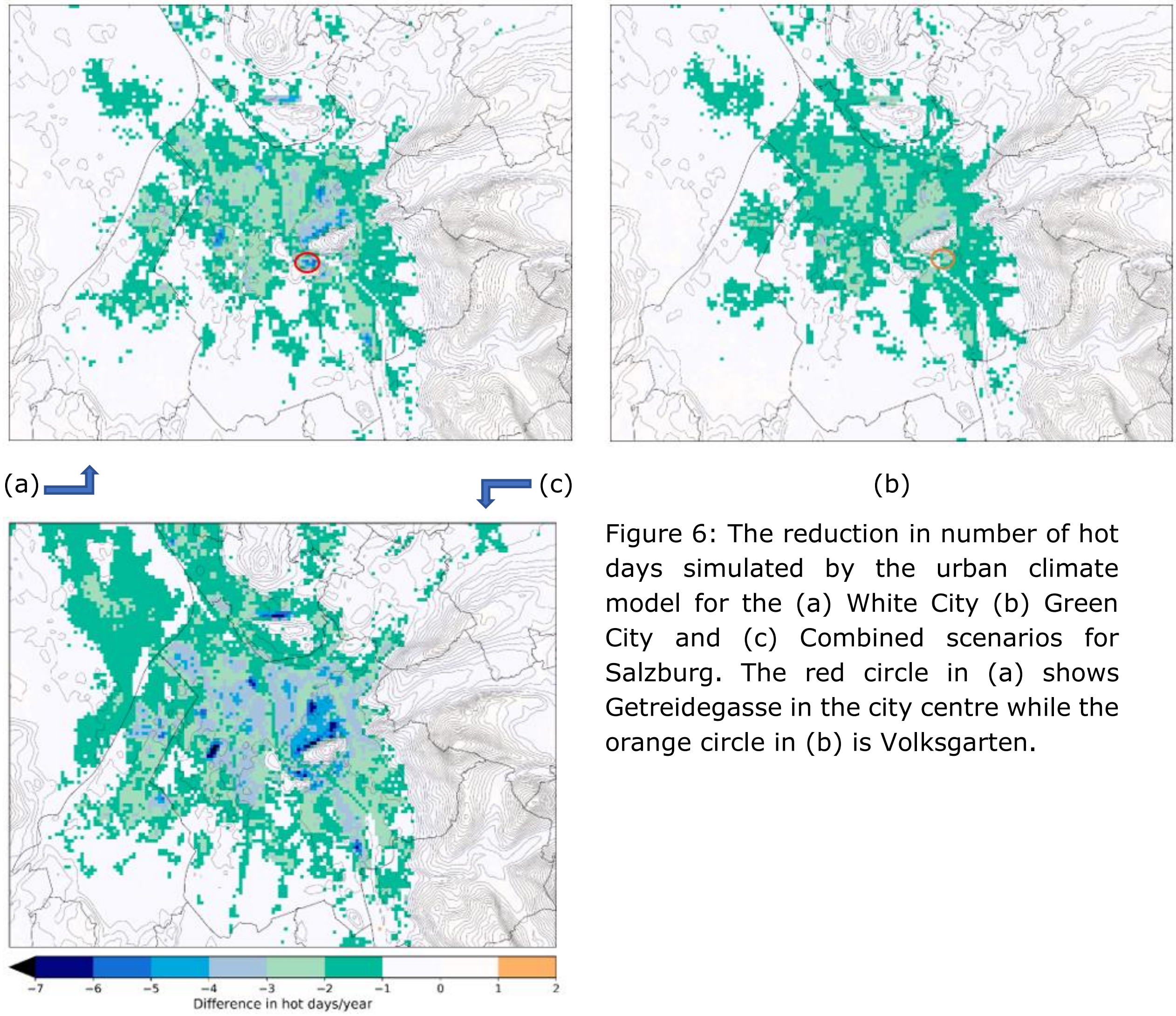


Figure 6: The reduction in number of hot days simulated by the urban climate model for the (a) White City (b) Green City and (c) Combined scenarios for Salzburg. The red circle in (a) shows Getreidegasse in the city centre while the orange circle in (b) is Volksgarten.

The urban climate model outputs for all adaptation scenarios can be viewed online from the ADAPT-UHI website from the 'Results' page of each pilot city while the results are summarized in factsheets, which can be downloaded from the website.

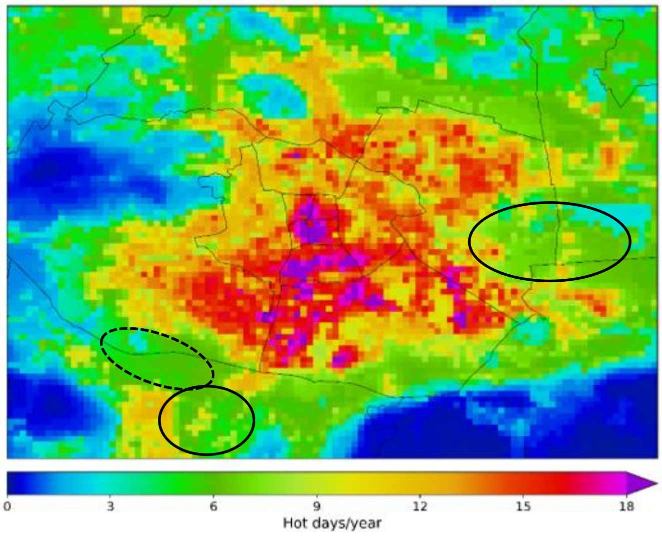
Additional scenarios were then run for each city. In the case of Mödling, the modelling was extended beyond the city to the nine neighboring districts (Gemeinden). Using a future climate projection based on RCP8.5, the increase in HD over the next three decades (2021-2050) was evaluated. Note that there is very little difference between RCPs 4.5 and 8.5 until 2050 (see Oswald et al., 2020). The effects of the Combined scenario in reducing the number of HD were then simulated. Table 2 shows the absolute values of HD (average/maximum) for (a) the future scenario if no adaptation measure is implemented, (b) if only the city of Mödling implements these measures, and (c) if all the districts implement the combined measures. The results show that if the measures are implemented in all neighboring districts, the effect is much larger in Mödling but also larger in each of the neighboring districts compared to the situation where measures are implemented only in the city of Mödling. Hence, a cooperation between neighboring districts in tackling climate change adaptation has clear benefits.

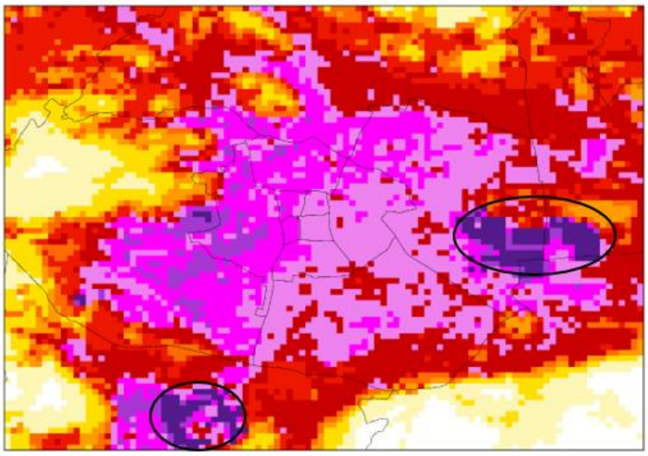
Table 2: Reduction in the number of hot days (HD, $T_{max} \geq 30°C$ - average and largest reduction) for the different adaptation scenarios as percentage reduction and absolute number of HD in each pilot city

Municipality, place (inhabitants 1.1.2015)	(a) HD per year for RCP8.5 2021-2050	(b) HD per year if measures are implemented in only the city of Mödling	(c) HD per year if measures are implemented in all municipalities of Mödling district
	Average over the center of the municipality / Maximum value		
Mödling, Freiheitsplatz	26.6	20.1	19.8
Mödling, Hyrtl Park	16.1	13.8	10.2
Mödling (20 495)	21.6 / 29.7	17.0 / 25.9	15.5 / 24.5
Perchtoldsdorf (14 754)	15.0 / 22.1	14.5 / 21.9	9.8 / 18.5
Gießhübl (2 213)	7.1 / 12.0	6.8 / 11.6	4.6 / 8.2
Hinterbrühl (4 040)	7.4 / 15.7	7.2 / 15.5	5.1 / 12.1
Brunn am Gebirge (11 509)	19.4 / 31.6	19.2 / 31.5	13.9 / 27.8
Maria Enzersdorf (8 691)	19.4 / 27.4	18.2 / 26.6	13.6 / 20.6
Gumpoldskirchen (3 748)	17.6 / 29.2	17.6 / 28.6	12.2 / 19.3
Vösendorf (6 571)	16.1 / 27.1	16.2 / 27.4	12.5 / 21.4
Wiener Neudorf (8 932)	22.2 / 29.3	22.0 / 29.0	16.7 / 23.9
Guntramsdorf (9 111)	23.0 / 34.5	23.0 / 34.8	17.4 / 27.2
Hennersdorf (1 410)	18.6 / 28.8	18.7 / 29.1	15.0 / 24.1
Biedermannsdorf (2 846)	19.5 / 30.5	19.6 / 30.6	14.9 / 24.4
Laxenburg (2 844)	17.1 / 30.9	17.3 / 31.8	13.4 / 25.0

A further scenario was also run for Klagenfurt based on future building plans for the region provided by IPAK. New buildings (i.e., residential and commercial) will be constructed, and afforestation will be undertaken, mainly in the eastern and southern (Viktring) part of the city, which are shown as black ellipses in Figure 7. Figure 7a shows the average annual number of HD for 1981-2010. To estimate possible future urban climate scenarios for Klagenfurt, model outputs from different Regional Climate Models under RCP4.5 for the time period 2021-2050 were used; the increase (or difference) in HD is shown in Figure 7b. While the increase in urban areas (i.e., inner districts) is quite similar, the increase is enhanced where new buildings are planned (black ellipses, which were previously annual crops).

Figure 7c shows the effect of the Combined adaptation scenario implemented with current as well as future planned buildings and afforestation. The intensity and spatial extent of the cooling is quite pronounced as the entire southern part of the city remains at the current level of HD. Moreover, the sustainable construction methods associated with the new planned buildings will mitigate the heat load by up to 5 HD. In summary, the city of Klagenfurt remains at around the same level of HD in 1981-2010 until 2050 if the combined adaptation measures are implemented. Future building plans will increase the number of HD, but the sustainable construction methods to be used will mitigate the additional urban heat load.





(a)

(c)

(b)

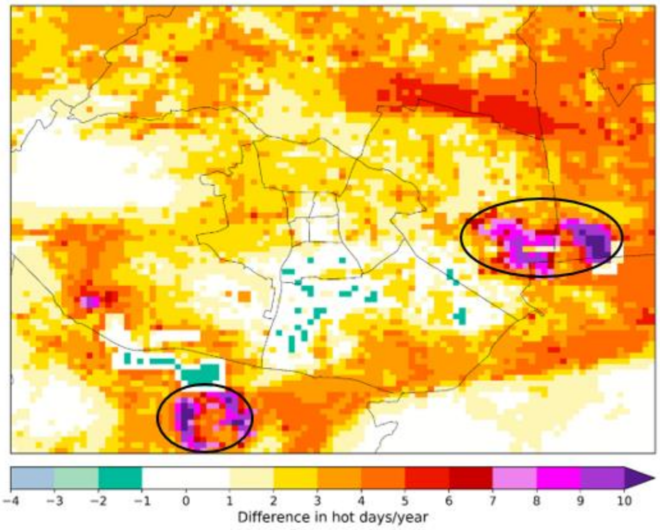
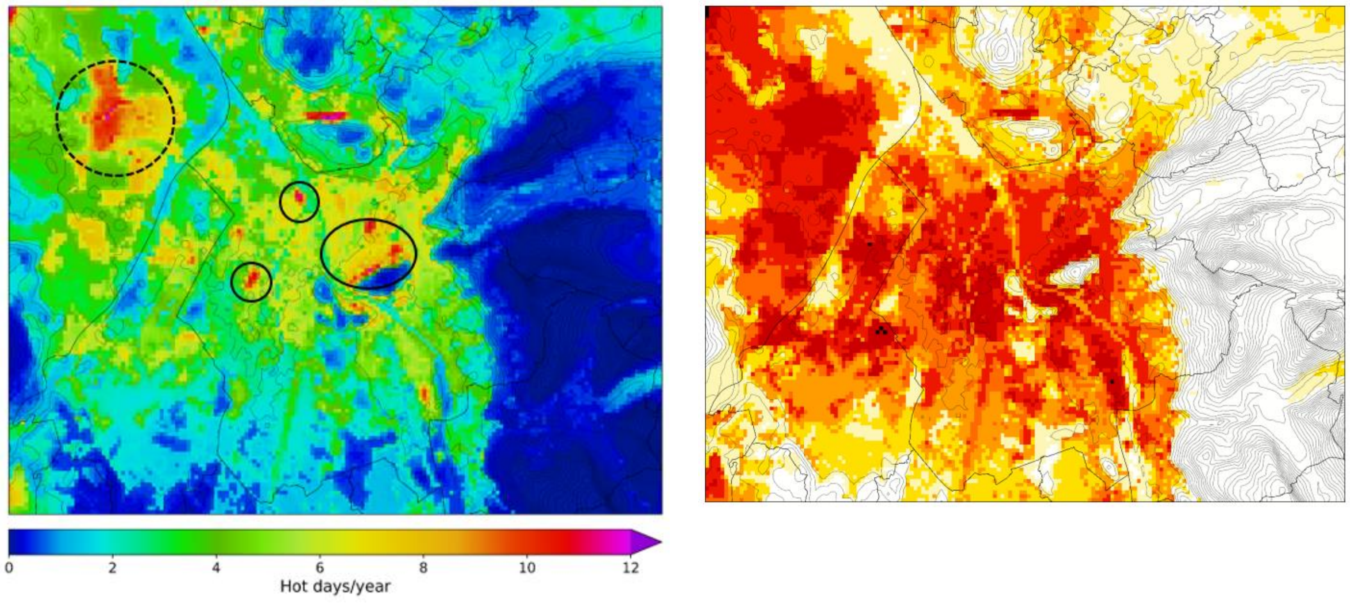


Figure 7: (a) The average annual number of hot days (HD) in Klagenfurt for 1981-2010. The increase (or difference) in HD in 2021-2050 for RCP4.5 (b) without and (c) with implementation of a Combined scenario that includes future building developments and an area of proposed afforestation.

A similar scenario was also run for the city of Salzburg. Figure 8a shows the average annual number of HD for 1981-2010. While most parts of the city reach values between 4 and 8 HD, single areas such as the Messezentrum, the commercial area in the east and parts of the city center (shown as black circles) stand out with 10 HD and above. Figure 8b shows the increase in HD for RCP4.5 for the period 2021-2050. Green urban areas such as the Kapuzinerberg and

Mönchsberg stay at the same level of HD without any adaptation measures, but almost the entire city increases by up to 6 HD (i.e., 60-90% more). Figure 8c shows the effect of the Combined adaptation scenario implemented with the current buildings. The intensity and spatial extent of the cooling is quite pronounced, i.e., almost the entire city remains at the current level of HD. Furthermore, the previously mentioned dense urban areas become a little bit cooler than today. Hence, the city of Salzburg remains at around the same level of HD in 1981-2010 until 2050 if the combined adaptation measures are implemented. The future scenario shows that dense urban areas (Schallmooser Hauptstraße, Reithofferstraße) can be even lower (i.e., cooler) than the current heat load. Moreover, Salzburg is on the border of Germany and one can see that Freilassing in Germany also has lower values of HD. Similar to the Mödling case, this demonstrates that cooperation across borders would be beneficial.



(b)

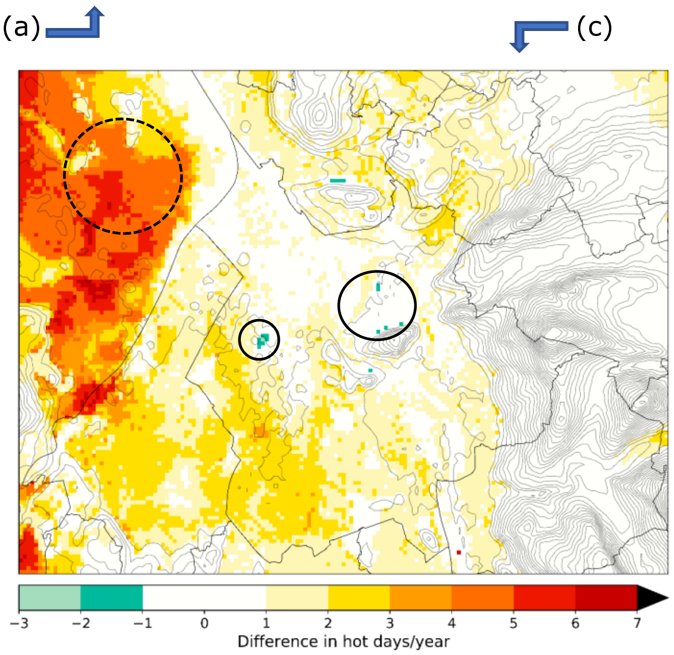
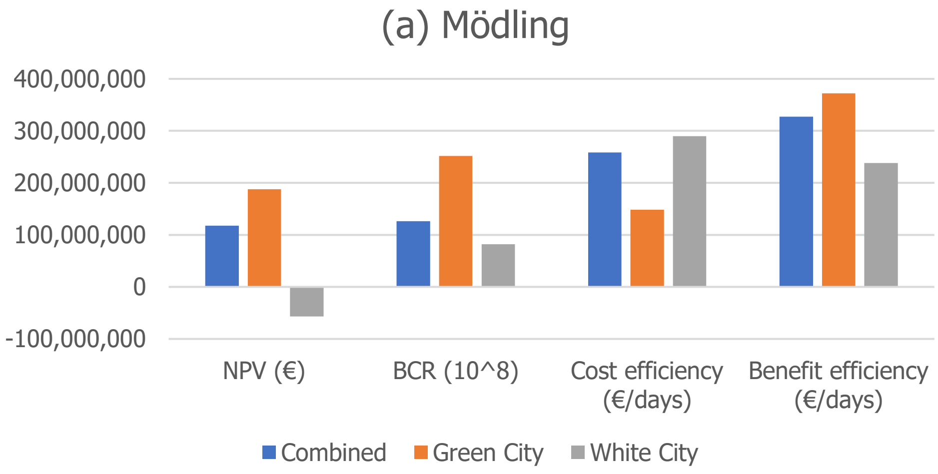
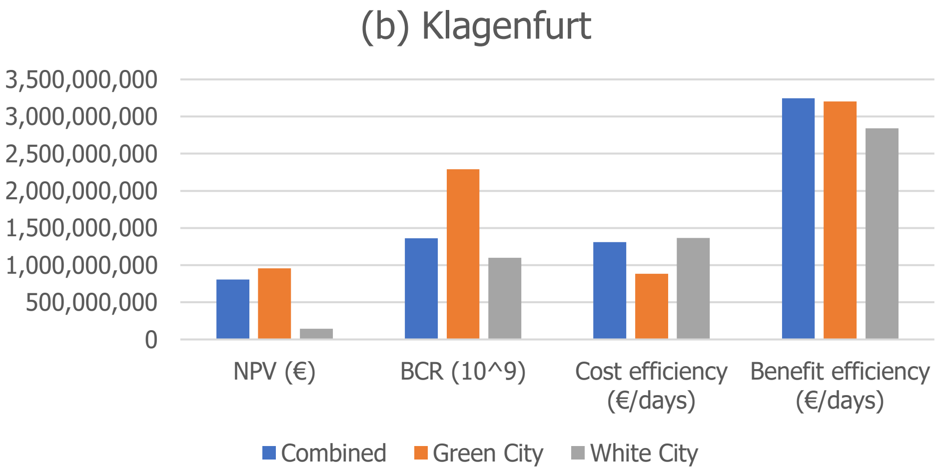


Figure 8: (a) The average annual number of hot days (HD) in Salzburg for 1981-2010. The difference in HD in 2021-2050 for RCP4.5 (b) without and (c) with implementation of a Combined adaptation scenario. Black circles/ellipses show parts of the city and commercial areas.

3 Cost-Benefit Analysis

The results of the cost benefit analysis for the White City, Green City and Combined scenarios are shown in Figure 9.


(a) Mödling


(b) Klagenfurt

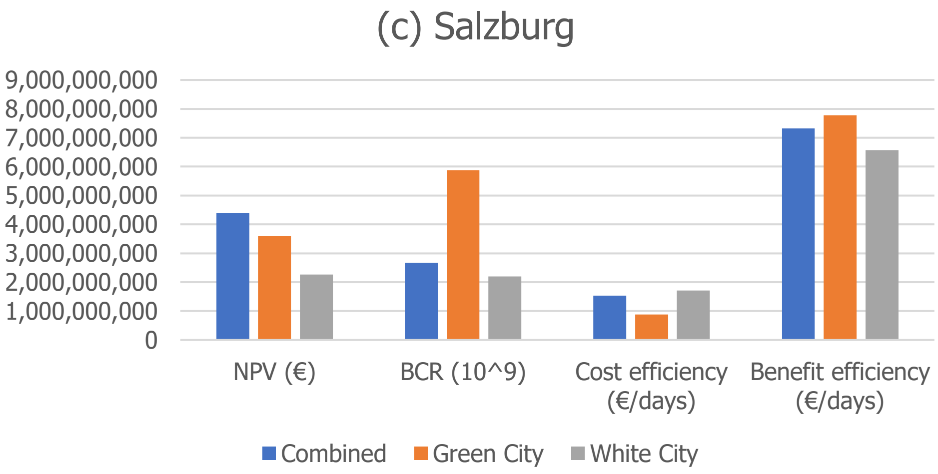

(c) Salzburg

Figure 9. Cost-benefit indices of the Combined, Green City and White City scenarios for (a) Mödling (b) Klagenfurt and (c) Salzburg.

When the Net Present Value (NPV) is above 0 and the Benefit to Cost Ratio (BCR) is above 1, then the benefits outweigh the costs. Note that the BCR in Figure 9 is expressed as an exponent so as to plot the values of all indicators on the same graph. The results from Figure 9 show that NPV is greater than 0 and BCR is greater than 1 for all scenarios (except the White City scenario for Mödling) and all cities, indicating that the benefits generally outweigh the costs.

The Green City scenario for Mödling achieved the highest benefit efficiency, despite the high costs associated with this scenario, demonstrating the numerous additional benefits from the ecosystem services. The White City scenario had lowest costs but this scenario resulted in a negative outcome. Similar results to Mödling were achieved for both Klagenfurt and Salzburg in the comparison of the Green City scenarios (see Figure 9b). The high costs of the Green City scenarios equally brought about higher benefits, leading to higher benefit efficiencies. The lower costs associated with the White City scenarios resulted in lower BCRs but higher cost efficiencies for the White City scenario for all cities. However, in the case of Klagenfurt, the combined scenario had the highest benefit efficiency, due to the relatively low reduced annual number of hot days in the Green and White City scenarios (~0.5 hot days on average). Furthermore, only in the case of Salzburg was the NPV the highest for the combined scenario of measures, which reflects the high sensitivity of the population to temperature in the heat-related benefits.

A sensitivity analysis was performed using a Monte Carlo simulation with 10,000 iterations to generate a set of cumulative probability curves to determine the risk of achieving the Combined scenario. The probabilities of a project obtaining a positive NPV were 88%, 73% and 100% for Mödling, Klagenfurt and Salzburg, respectively. Therefore, the results for Mödling and Salzburg are very robust in terms of obtaining a positive outcome. For Klagenfurt, the lower property prices compared to Mödling and Salzburg became very relevant in testing the sensitivity of the property value increase. Although Klagenfurt achieves a higher BCR than Mödling, for example, the variability in parameters leads to higher risk in the combined scenario for this city.

The results are available for each city as a factsheet, which can be downloaded from the individual city Results pages on the ADAPT-UHI website.

4 Recommendations for Climate Change Adaptation

The ADAPT-UHI team produced a general set of recommendations as a factsheet, available on the Outputs page of the ADAPT-UHI website and then turned into a more visually appealing brochure, currently only available in German; this will be translated to English during the summer of 2020.

For each city, we also produced a set of ten city-specific recommendations for incorporation into city plans or adaptation strategies, available as factsheets on the Results pages of the ADAPT-UHI website for each pilot city. Below is the list of recommendations provided to the city of Mödling as an example (or as a factsheet in this link):

Ten Recommendations for Climate Change Adaptation Measures for the City of Mödling

1. Expansion of sustainable irrigation and sustainable design of public green spaces
    - Optimize irrigation for extreme heat periods (e.g., deep root irrigation in trees, pipe cross sections, drip irrigation close to the ground, ensure sufficient capacity exists in the municipality)
    - Implement decentralized water storage for trees (e.g., Sponge city, Aqua Bag)
    - Ensure sufficient infiltration areas for trees and shrubs (i.e., soil moisture from rain)
    - Implement demand-oriented and water-efficient irrigation of green areas (through sensors and Geographic Information Systems - GIS), which would depend on the type and condition of the vegetation/trees, location factors (e.g., root area, soil, microclimate, root and groundwater depth) and weather (air temperature, wind and solar intensity)
    - Change to heat, dry and pest resistant trees (e.g., silver lime) and shrubs with high potential leaf area indices (e.g., winter bark, pedunculate oak)
    - Densify vegetation in existing green areas (i.e., parks, street spaces, squares, green parking lots)
    - Create new green areas through unsealing (with a focus on public places)
2. Sustainable design and irrigation of private green spaces
    - Target advice to specific groups (e.g., private and institutional forest and garden owners, companies in industrial and commercial areas, farmers, forestry companies)
    - Implement a tree protection program (similar to Vienna)
    - Initiate a tree support program for new trees in gardens (similar to the city of Graz)
    - Conserve green areas/or unseal private parking spaces and inner courtyards by means of green area target values in the development plan, considering green roofs, façades/balcony greening and blue areas
3. Construction / renovation of green roofs on a minimum flat roof area of 200 m^2 (adapted from NÖ ROG)
4. Expansion of the subsidy program for green roof areas, as well as for façades and vegetated balconies
5. Definition of a minimum value of 0.50 to 0.70 for the reflectivity of new roof surfaces and road/path surfaces (with consideration for areas with special designations such as monuments, the old town center, etc.)
6. Increased shading in public areas through addition of trees, arbors, awnings and solar panels (with a minimum reflection), as well as by raising the maximum building height

7. Creation of new cool public outdoor lounges with green areas and water as well as additional drinking fountains in pedestrian hot spots (e.g., train stations)
8. Development of a cold air strategy for Mödling (green belts, cold air preparation areas, cold air and supply air channels, shaded blue areas with moving water)
9. Integrated collection, monitoring, management, assessment and planning of green and blue areas and other factors (e.g., shading, low absorption roofs) to enhance city cooling. This can be done using a GIS and Urban Climate Quality Mapping (UCQM). UHI adaptation should also be integrated in local development concepts and be facilitated through provision of the necessary databases and capacities.
10. Regional cooperation between the neighboring municipalities and the district in the implementation of adaptation measures to urban heat islands, i.e., in joint action planning and spatial planning (protection of forest areas - especially against fire, development and design of industrial and commercial areas, large construction projects, regional development concepts, collection and sharing of databases).

5 UHI Risk Index

The UHI Risk Index (and the UHI Hazard Index which is used to calculate the risk index) were produced for all of Austria at a 100x100 m^2 resolution. The results showed that areas with an identified heat-related level of hazard cover around 10% of Austria. Considering only these areas, just under 10% fall within the high and very high hazard categories. The UHI Hazard Index is then translated into risk by considering vulnerable populations and areas of employment, which shows a higher level of UHI risk than the hazard alone would indicate. Of those areas at risk in Austria, around 30% are in the high and very high risk categories, with a further 20% in the medium risk category.

The UHI Risk and Hazard maps can be visualized using the online mapping application (see Table 3), with more information available as a general and city-specific factsheet, downloadable from the ADAPT-UHI website. The two indicators can be downloaded as geotiffs from: http://dare.iiasa.ac.at/86/.

Extracts were then made for each of the pilot cities. Figure 10 shows an example of the UHI Risk Index for the city of Mödling and the surrounding districts. Around 50% of Mödling is at risk from the UHI effect. Of those areas at risk, around 80% of these fall within the high to very high category. Results were also generated for Klagenfurt and Salzburg with 31% and 50% at risk from the UHI, respectively, and 60% and 74% falling within the high to very high category, respectively.

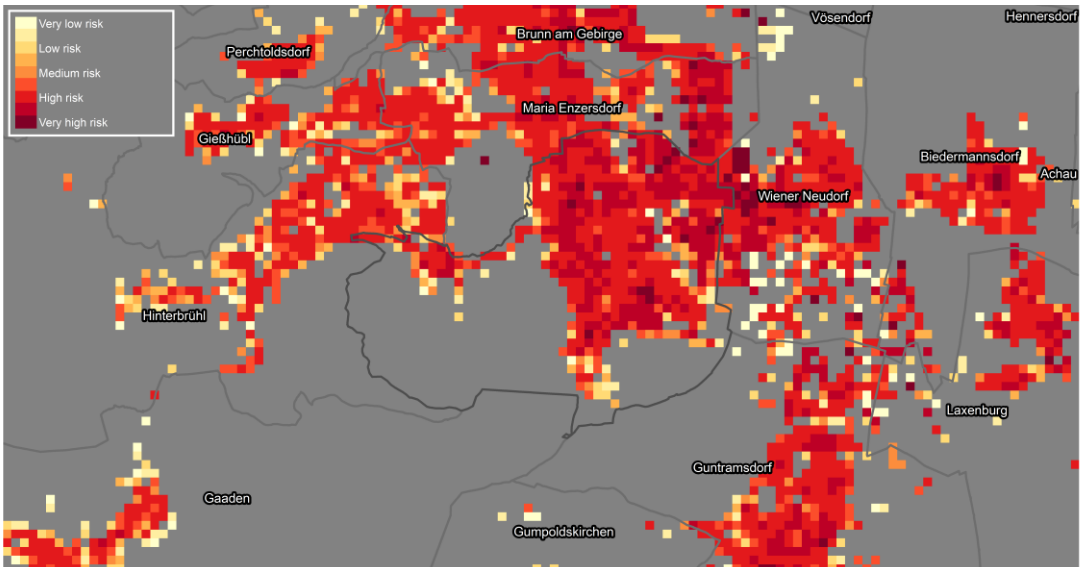


Figure 10: The UHI Risk Index for the city of Mödling produced in the ADAPT-UHI project

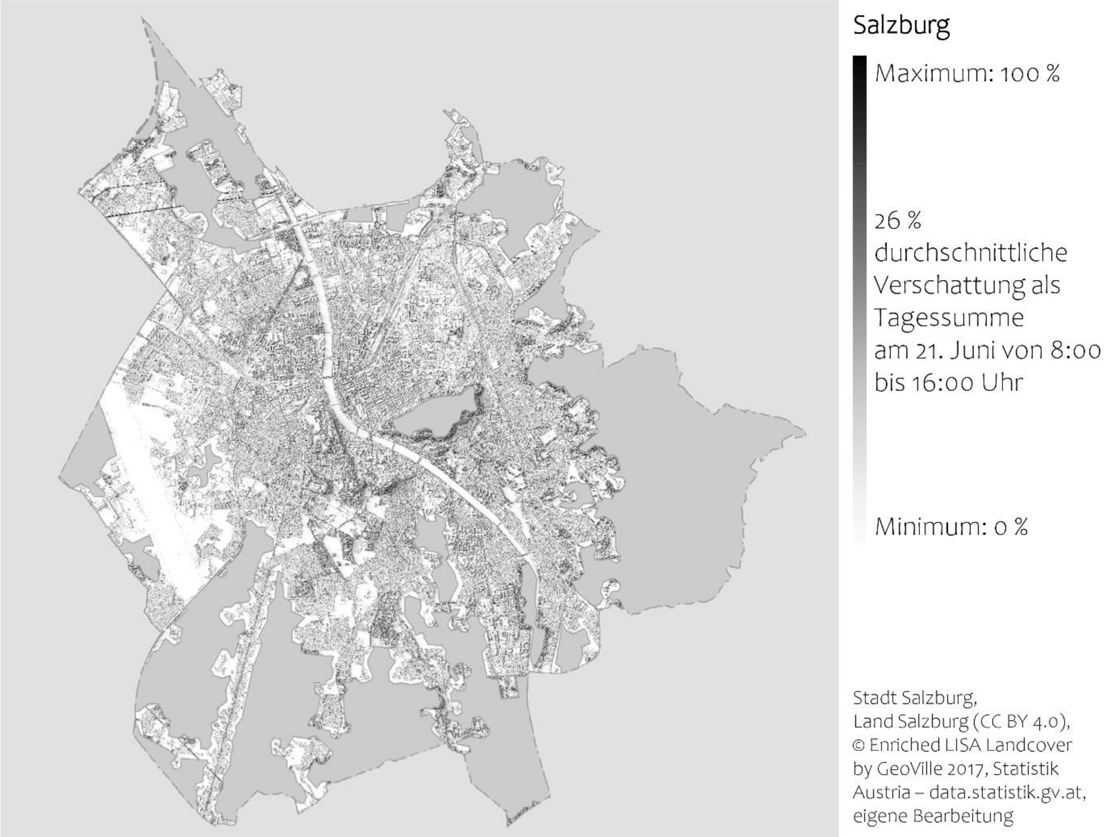
6 Urban Climate Quality Maps

A set of Urban Climate Quality Maps were produced for each of the pilot cities. They consist of the following layers:

- Sum of daily shading (from 8:00 a.m. to 4:00 p.m. on June 21) as a percentage of the full shading over the entire observation period [%] showing:
  - where shade is provided from buildings, vegetation and overall; and
  - where traffic areas and buildings are shaded.

- Estimation of the potential evapotranspiration of green areas and water bodies estimated as water per day and square meter of floor area [g H2O / (m^2/day)] on the first, 14th and 63rd successive hot day without precipitation and then:
  - Conversion to evapotranspiration cooling [Wh/(m^2/day)]
  - Conversion into cooling capacity airflow [(m^3/K) /(m^2/day)]

An example of the map of shading produced for the city of Salzburg is shown in Figure 11. All the maps can be found in the brochure produced on the Urban Climate Quality Maps, which appears on the Outputs page of the ADAPT-UHI website (see Table 3).



Stadt Salzburg,
Land Salzburg (CC BY 4.0),
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Austria – data.statistik.gv.at,
eigene Bearbeitung

Figure 11: An example of the map of shading produced for the city of Salzburg in the ADAPT-UHI project

To summarize the project results, Table 3 provides the outputs given to the pilot cities (as well as all data sets in GIS format). However, these outputs are also of interest to a broader audience such as urban planners in other Austrian cities (as well as internationally), researchers in climate change adaptation, health and urban planning, architects, the building industry, etc.

Table 3: List of outputs from the ADAPT-UHI project (found on the ADAPT-UHI website)

Output/Result	**Type of Output**	**Location of outputs**
General Recommendations	Factsheet + Brochure	https://www.adapt-uhi.org on the Outputs page
Presentation from the final ADAPT-UHI Workshop	Presentation	
Results from the key question session in the final ADAPT-UHI Workshop	Factsheet	
Urban Climate Quality Maps	Brochure (German only)	
UHI Risk Index	General factsheet and one per city	
UHI Risk Index maps	Online mapping application	

Output/Result	**Type of Output**	**Location of outputs**
UHI Risk Index data	Geotiffs	Available from: http://dare.iiasa.ac.at/86/
Adaptation scenarios and cost benefit analysis	Factsheet, one per city	https://www.adapt-uhi.org on the Mödling, Klagenfurt and Salzburg Results pages
Adaptation scenarios for each city in number of summer days and number of hot days	Online mapping application, one for summer days, one for hot days, available for each city	
Adaptation scenarios for Mödling's neighboring districts (Gemeinden)	Factsheet, only for Mödling	https://www.adapt-uhi.org on the Mödling Results page
Ten recommendations for climate change adaptation	Factsheet, one per city	https://www.adapt-uhi.org on the Mödling, Klagenfurt and Salzburg Results pages
Presentations from the final meetings with each city	Presentation, one per city	

5 Conclusions and Recommendations

The ADAPT-UHI project supported three small- to medium-sized cities in Austria (Mödling, Klagenfurt and Salzburg) in terms of climate change adaptation. Using an urban climate model, various adaptation scenarios were run to examine the effect in reducing the UHI across each city. These scenarios included the implementation of white measures (increasing the reflectivity or albedo of roofs, walls and road surfaces – referred to collectively as the White City), green measures (increasing green roofs, greenspaces, trees, etc. – referred to collectively as the Green City) and a Combined scenario including all measures. These adaptation scenarios were then coupled with a cost-benefit analysis that took both heat-reduction related benefits and ecosystem service benefits into account.

There are several conclusions arising from the project. The first set are derived from the urban climate modelling exercise. The UHI effect was first quantified for each city based on the recent climate (1971-2000) as the average annual number of summer days (SD, $T_{max} \geq 25°C$), spatially-averaged across the model domain. The results showed that this was 54.5 SD for Mödling, 62.7 SD for Klagenfurt and 43.9 SD for Salzburg. With future climate projections, the average annual number of SD will increase from 28-55% under RCP4.5 and 30-112% under RCP8.5 in the pilot cities for the time period 2071-2100 in comparison to period 1971-2000. Thus, the UHI effect will increase considerably in the future in all three pilot cities.

The urban climate model was then used to simulate the effect of implementing a range of adaptation measures. The results showed that the Combined adaptation scenario provided the largest reductions in the UHI effect (measured in hot days, HD) compared to the Green City, White City or individual adaptation scenarios. Of the White and Green City scenarios, the White City produced the largest average reductions in all three cities. The most effective individual adaptation measure in all three cities was doubling the roof albedo.

Additional scenarios were then run for each city. The Combined scenario, which included all neighboring districts of Mödling under a future climate (2021-2050) and RCP8.5, showed that if all districts implement the Combined adaptation measures, then the reductions in the number of HD would be greater in Mödling as well as in all neighboring districts compared to the situation in which only Mödling implemented the measures. This additional scenario indicates that regional cooperation would be beneficial in addressing climate change and recommends that further dialogue on climate change issues takes place at both an urban and regional scale.

An additional scenario for the city of Klagenfurt to take future climate and new building developments into account showed that the city will remain at around the same level of HD in 1981-2010 until 2050 if the combined adaptation measures are implemented. Future building plans will increase the number of HD, but the proposed sustainable construction methods that will be used will serve to mitigate the urban heat load.

An additional scenario for the city of Salzburg showed that the city will remain at around the same level of HD in 1981-2010 until 2050 if the combined adaptation measures are implemented, similar to the situation in Klagenfurt. Moreover, the Combined adaptation scenario had positive impacts on Salzburg‘s neighboring town of Freilassing in Germany, which further demonstrates that cooperation across borders would be beneficial. Thus, the climate change dialogue should not only take place at a regional level but also transnationally.

Finally, the urban climate modelling results were coupled to a cost-benefit analysis, which showed that for almost all scenarios, the benefits outweigh the costs, particularly when taking both heat reduction-related benefits and ecosystem service benefits into account; the exception was the White City scenario for Mödling, partly because this scenario does not have ecosystem service benefits.

These model findings, in addition to current best practices, were turned into a series of general and city-specific recommendations provided to each pilot, which can be incorporated into smart city plans and climate change adaptation strategies. These recommendations are available from the ADAPT-UHI website (https://www.adapt-uhi.org).

Two further urban planning tools were then developed in the project: the UHI Risk Index at a 100x100 m^2 resolution for Austria, and Urban Climate Quality Maps, which indicate areas of shading and cooling across the city. The results of the UHI Risk Index showed that 30% of those areas at risk in Austria (which covers around 10% of the country) fall within the high to very high risk categories, with a further 20% in the medium risk category. For the pilot cities, 80%, 60% and 74% of Mödling, Klagenfurt and Salzburg fall within the high to very high risk categories, respectively. Hence, urban planners can use this tool to determine which areas could be targeted for planning or policy interventions. Similarly, the Urban Climate Quality Maps provide a new planning instrument for addressing climate change.

In the future, the urban climate modelling approach could be extended to other cities in Austria as well as internationally. Funding such an approach could be possible through various EU funding mechanisms. Other urban climate models could be considered such as the openly available PALM-4U model. The advantages would be the ability to model at a higher spatial resolution as well as inclusion of urban chemistry, i.e., pollution modelling and health-related applications.

The Urban Climate Quality Mapping exercise could also be extended in the future. This would involve turning the outputs into tailored applications for each city. To date, the cost-benefit framework has rarely been used by cities to monetize adaptation measures. The approach developed in the ADAPT-UHI project could be extended methodologically as well as more practically into a decision support tool for urban planners. Hence, the ADAPT-UHI project identified several avenues for future research.

C) Details of the Project

6 Methodology

The ADAPT-UHI project involved the application of a number of different methodologies, which are outlined below.

Working with the Pilot Cities

Before the project started, three cities were recruited to participate in the ADAPT-UHI project: Mödling, Klagenfurt and Salzburg. Hence, contacts with the urban planning departments in each of the three cities were established prior to the start of the project. A series of meetings were held with each pilot city throughout the project for the purpose of user requirements, co-design of adaptation strategies and development of recommendations, as follows:

- **User requirements meeting:** The purpose was to understand the status of each city’s strategy on urban development, climate change adaptation and mitigation, and the desired outcomes for the urban planning department. The city-specific data required for the urban climate model were also discussed, and plans were made for data transfer to the project consortium.
- **Meeting to present intermediate results:** The results from the urban climate model were presented to each pilot city including model validation, future climate projections and adaptation scenarios. Feedback from the cities was used to tailor further adaptation scenarios and project outputs.
- **Meeting to present final results:** The final results from the adaptation sccenarios were presented along with the cost-benefit analysis, the UHI Risk Index, the Urban Climate Quality Maps and the general and city-specific recommendations. Based on feedback from the cities, the recommendations were adjusted accordingly.
- **Final ADAPT-UHI project workshop:** All the results from the project were presented to a wider audience, which included a session on brainstorming key questions related to climate change adaptation and mitigation.

Urban Climate Modelling

The urban climate model used by ZAMG in the project was the microscale MUKLIMO_3 model, provided by the German Meteorological Service (Deutscher Wetterdienst). The model simulates, among other parameters, atmospheric temperature, humidity and wind flow in urban areas on a three-dimensional grid (Sievers 1990; 1995). The cuboid method is then used for calculation of the climate indices (Früh et al. 2011).

The model requires a digital elevation model and land use information as inputs: (i) buildings and impervious surfaces, (ii) trees, (iii) low vegetated areas, and (iv) water. These inputs were supplied by each pilot city in addition to information used from the Copernicus land monitoring service and the LISA land cover data set. The model simulated the urban climate at a 20 m resolution for Mödling and a 100 m resolution for Klagenfurt and Salzburg (although the latter two city centers were also modelled at a 20 m resolution). Once the model parameters were set, the model is driven by meteorological data for specific daily weather situations in which excessive urban heat load occurs. Observations or reanalysis data for the past are used in the cuboid method to calculate long-term climate indices. The reanalysis data are given on a grid that runs through the atmosphere, having typically some hundred km horizontal grid spacing and about 20-60 vertical layers. The NCAR-NCEP (Kalnay et al. 1996) or the ERA40 reanalysis (Uppala et al. 2005) data meet the requirements needed to model the present day climate with a Regional Climate Model (RCM). With such data sets for the past, RCMs were employed to derive local scale climate conditions at a resolution of a few km (EURO-CORDEX project). The observations or results from RCMs served as background climate conditions for MUKLIMO_3 and the cuboid method. Although the modelling methodology can produce several different outputs, for the purpose of ADAPT-UHI, the following were generated for each city: mean annual number of summer days ($T_{max} \geq 25°C$) and mean annual number of hot days ($T_{max} \geq 30°C$).

The modelled climate indices were then validated by comparing the results with available observations at nearby weather stations. This included weather stations at the airports of Klagenfurt and Salzburg and the nearby town of Gumpoldskirchen in the case of Mödling. The climate indices related to extreme heat load were calculated based on the temperature data and compared with the modelling results based on the MUKLIMO_3 model for two time periods (1971-2000 and 1981-2010). Biases in the number of summer and hot days simulated by the model compared to long-term observational time series from weather stations in or near the cities were shown to be less than ±10%, which means the model results were valid.

Once the model was validated for each pilot city, time series of the key meteorological parameters were extracted from RCMs for different climate scenarios (i.e., for Representative Concentration Pathways (RCPs) of 4.5 (peak in emissions by around 2040) and 8.5 (worst case scenario)) to calculate the mean annual number of summer and hot days for two time periods in the future: 2021-2050 and 2071-2100.

Finally, a series of different adaptation measures were implemented in the model by changing model parameters in relevant land cover types. Table 4 outlines the set of white measures (those that increase the reflectivity or albedo of the surface), green measures (those that cool the ambient temperature) and their combination as implemented for each city. The results were provided as average and maximum values of summer and hot days for each city as well as the distribution of summer and hot days across the city (as maps) so that they could be compared to the situation in 1981-2010. These results were also expressed in terms of the difference (or reduction) in the number of summer and hot days based on each scenario so that the effects of each adaptation measure (or combined measures) in reducing the UHI could be seen.

After the intermediate meeting with each pilot city, additional city-specific tailored scenarios were implemented to reflect future building developments including future climate scenarios, changes in land cover, e.g., addition of forested areas or water channels, and a scenario for Mödling that considered the effects of implementing the combined scenario to the nine neighboring districts (Gemeinden) compared to implementing these in Mödling alone.

Table 4: Adaptation scenarios simulated with the urban climate model for each pilot city

Adaptation scenarios	**Description**	**Changes to model parameters**
Double roof albedo	Increase the reflectivity of the roof, e.g., use lighter roofing materials	From 0.2 to 0.5 (urban land use classes)
Double wall albedo	Increase the reflectivity of the wall, e.g., paint the wall a lighter color or use a lighter rendering	From 0.3 to 0.5 (urban land use classes)
Double street albedo	Use more pervious paving or paint the streets lighter colors	From 0.2 to 0.4 (urban land use classes plus parks and sport areas)
White City (above three albedo scenarios combined)	**Increase reflectivity of roofs, walls and streets**	**Combination of three above scenarios**
Decrease sealed areas	Implement grassland and parks instead of paved areas in the city	-30% (urban land use classes)
Increase green roofs by 50%	Add green roofs to 50% of buildings in suburban areas of Mödling	50% (urban land use classes except very dense ones)
Increase the number of trees by 50%	Plant more trees in public areas	+50% (near streets, railways and in parks and other vegetated areas)
Decrease unvegetated, pervious areas	Add grass and parks to bare soil areas in the city	From 85% to100% (urban land use classes)
Green City (above four scenarios combined)	**Decrease sealed areas, add green roofs, increase trees and unvegatated pervious areas**	**Combination of four above scenarios**
Combined Scenario (White City and Green City)	**Implement all adaptation measures from the White and Green City**	**Implementation of white and green city**

Cost-Benefit Analysis

In the original proposal, the idea was to provide some indicative costs for different adaptation measures as guidance for the pilot cities. Due to the involvement of PhD student Daniel Johnson through IIASA's Young Scientist Summer Program in year 2 of the project, a full cost-benefit analysis was undertaken on the White City, Green City and Combined scenarios.

The methodology for the cost-benefit analysis is shown in Figure 12. This approach is referred to as 'social cost-benefit analysis' as it takes both heat reduction benefits and ecosystem service-related benefits into account. As shown in Figure 12, different inputs were used in the analysis. Daily all-cause mortality counts for the three pilot cities for 2003-2017 and population data from 2017 on a 250m x 250m raster were purchased from Statistik Austria while the reference climate data were obtained from ZAMG, which included maximum daily temperature, mean daily temperature, precipitation, sunshine duration and air pressure from weather stations at or near to the pilot cities. These were used to develop temperature-mortality relationships for each of the pilot cities. This then allowed reductions in mortality to be determined with the implementation of the adaptation measures in the White City, Green City and Combined scenarios. Two other heat reduction-related benefits were calculated including reduced morbidity (or reductions in hospital stays) and reductions in productivity loss with reductions in the number of hot days based on the three scenarios.

On the ecosystem services side, a number of different benefits were quantified using data gathered on Austrian cities as well as values from the literature, including reductions in stormwater runoff with green roofs and unsealing of surfaces, creation of additional habitats improving biodiversity, decreases in pollution and CO_2 sequestration, the increased longevity of green roofs compared to traditional roofs, increases in property value with green roofs, and the heating and cooling savings from implementation of green roofs.

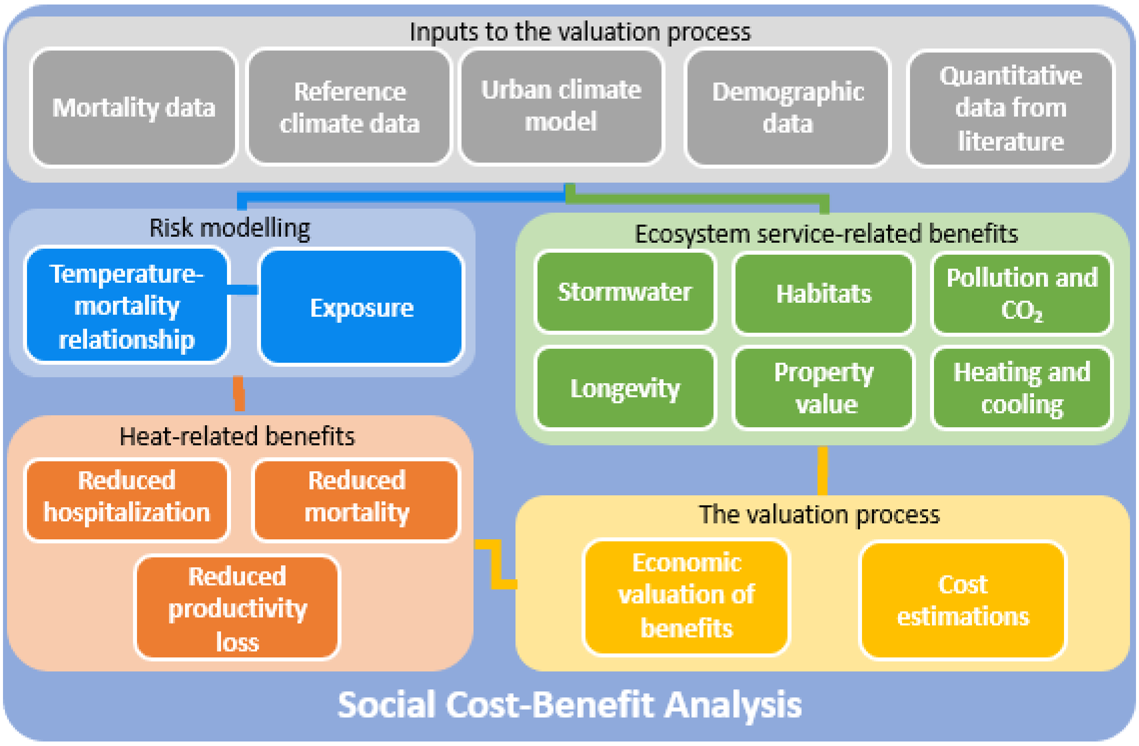

Figure 12: Methodology for the social cost-benefit analysis used in the ADAPT-UHI project

Unit cost estimates for each of the adaptation measures were obtained from the literature and from expert interviews with local planning authorities in Vienna, Austria. Cost-benefit indices were then calculated including the net present value (NPV), the benefit-cost ratio (BCR) and benefit efficiency and cost efficiency. An NPV above 0 and BCR above 1 indicate that benefits outweigh the costs. The efficiencies allow for comparisons across scenarios in terms of the ratios of the benefits and costs in relation to the reduction in the number of hot days. The analysis was conducted over a time horizon of 50 years followed by a sensitivity analysis using Monte Carlo simulation. Full details of the methodology will become available in Johnson et al. (in review).

Development of Recommendations on Climate Change Adaptation

This step involved translating the adaptation scenarios into a set of recommendations for each pilot city that could be incorporated into climate change adaptation strategies, smart city plans and where possible, building regulations. Implementation of the adaptation measures showed a reduction in the UHI effect during summer time, albeit to different degrees and at different locations across the pilot cities. Hence the recommendations were based on different white and green adaptation measures, current best practices and based on feedback and discussion with the pilot cities throughout the project.

Development of Other Tools

Two other urban planning tools were developed during the project that can aid the pilot cities in urban planning related to climate change: the UHI Risk Index and the Urban Climate Quality Maps; the methodology for their development is outlined below.

Urban Planning Tool 1 - UHI Risk Index

The idea behind the UHI Risk Index was a similar product developed in Germany at a 1 km^2 resolution prior to the start of the ADAPT-UHI project. However, the methodology for this index was developed during the ADAPT-UHI project, summarized in Figure 1. Four main types of inputs were used to generate the risk index: meteorological indicators related to heat load (provided by ZAMG), maps of land cover, information on settlements, and demographic indicators. These inputs were first divided into drivers that cause and reduce the heat hazard in urban areas, which is defined as the combination of heat waves and the UHI effect. Drivers that contribute to the heat hazard include three meteorological factors related to periods of high temperature (produced by ZAMG) and the amount soil sealing, available as a layer from the Copernicus land monitoring service. The drivers that reduce hazards include green and blue land cover that cools the air temperature as well as shading from buildings, available from the settlement input data. These drivers were then weighted based on expert knowledge and combined to produce the so-called UHI Hazard index at a 100 m resolution. Areas with no inhabitants and a soil sealing of less than 5% were masked out, i.e., they pose no hazard or risk due to the UHI. The UHI risk index is then calculated by additionally considering the population at risk, which is derived from a combination of demographic data (0-64 years, 65 years and above), the number of people employed at workplaces and the estimated duration that people stay outside in the heat. The population at risk is multiplied by the UHI Hazard Index to produce the UHI Risk Index map, which has been produced for all of Austria at a 100 m resolution.

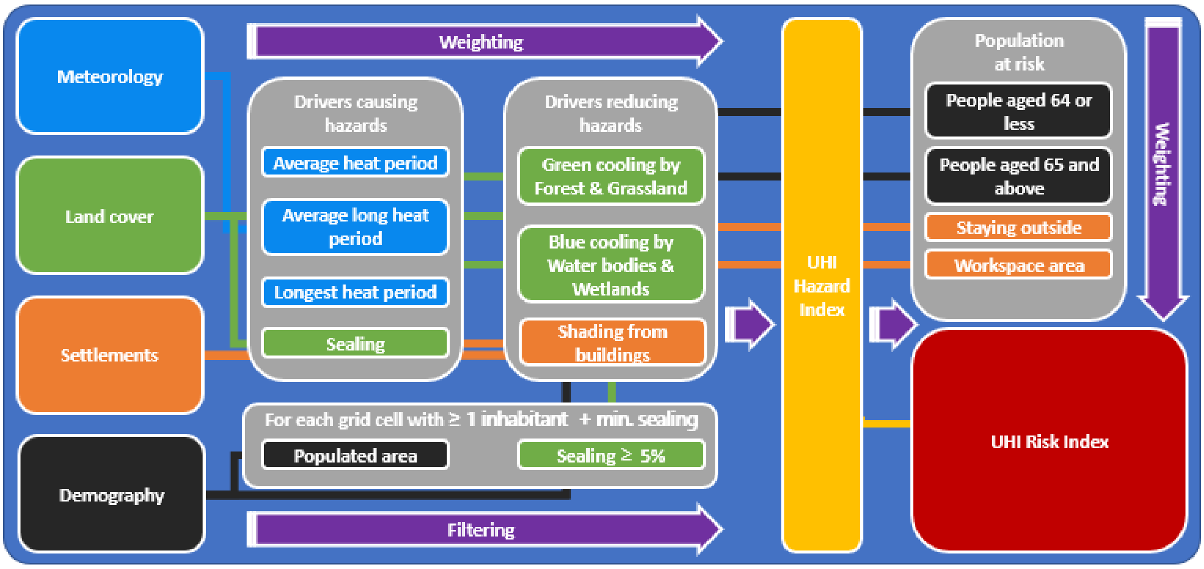

Figure 13: Methodology for calculation of the UHI Risk Index in the ADAPT-UHI project

A factsheet on the UHI Risk Index is available from the ADAPT-UHI website on the Outputs page or directly from this link:

https://eocs.blob.core.windows.net/adapt/FactsheetUHIRiskIndex.pdf

Urban Planning Tool 2 - Urban Climate Quality Maps

The final activity in this work package was the development of city greening quality maps, renamed during the project to Urban Climate Quality Maps. The main aim of these maps is to support cities in developing, protecting and managing green and blue areas within the city for improving human well-being and to bolster resilience during heat waves. The approach developed in the project focused on two main effects for improving comfort and decreasing health risks due to UHIs, which are shading and evaporation cooling. As inputs to the analysis, the buildings, vegetation, roads and water surfaces were obtained from the LISA land cover data set. The height of objects in the city (buildings, vegetation) was derived from the difference between a digital surface model and a digital terrain model of each city. The methodology is described in more detail below.

a) Shading of buildings by vegetation/shading of non-built up areas by vegetation: The shading calculations were performed using the UMEP Processor 4.3. Solar Radiation: Daily Shadow Pattern tool developed by Frederik Lindberg, with building, vegetation and road layers as inputs as well as the building and vegetation heights.

b) Evaporation cooling by green and blue areas and from additional activities/measures: The evaporation per leaf area on successive heat days without precipitation was calculated for 5 categories:

  - Vegetation over 5 m with good ground water supply and / or deep irrigation
  - Vegetation over 5 m without good ground water supply and without deep irrigation
  - Vegetation under 5 m with good ground water supply
  - Vegetation under 5 m without good ground water supply but with deep irrigation
  - Vegetation under 5 m without good ground water supply and without deep irrigation.

Four levels of surface irrigation were identified as follows:

- Intensive: over 70% to 100% of the target irrigation intensity
- Reduced: over 30% to 70% of the target irrigation intensity
- Insufficient: over 10% to 70% of the target irrigation intensity
- Without: up to 10% of the target value for the irrigation intensity.

The potential evapotranspiration, evapotranspiration cooling and the cooling capacity air flow were then derived for three scenarios of successive heat days without precipitation: 1 day, 14 days and 63 days.

A brochure on the Urban Climate Quality Maps (in German only) is available from the ADAPT-UHI website on the Outputs page or directly from this link:

https://eocs.blob.core.windows.net/adapt/UCQM_Broschuere_Final.pdf

7 Work Schedule and Time Plan

All the milestones in the project were met, although some were acheived later than outlined in the original propsal.

Red = Duration of the WP as outlined in the original proposal

Blue = The month(s) in which the milestone was met (or over multiple months for some activities)

Project months

Start: 19/03/2018 **End: 18/03/2020**

WP	**Description**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
WP1	**Project Management**	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
MS1.1	Interim project report													🟦											
MS1.2	Final project report																								🟦 +3
WP2	**User Requirements**	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																
MS2.1	User requirements from pilot cities obtained					🟦																			
MS2.2	Input data to run the urban climate model obtained from the pilot cities				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦													
MS2.3	City greening quality maps for the three pilot cities																							🟦	
WP3	**Urban Climate Modelling**	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥											
MS3.1	Austrian climate indicator maps generated											🟦													
MS3.2	UHI risk index map for Austria generated																			🟦					
MS3.3	Model parameters for each pilot city defined					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦												
MS3.4	Model results generated by the urban climate model for the current climate									🟦	🟦	🟦	🟦												
MS3.5	Model results validated and checked for plausibility												🟦												
MS3.6	UHI risk index results checked for plausibility																							🟦	
WP4	**Future Climate/Urban Planning Scenarios**													🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	
MS4.1	Results for future climate scenarios generated by the urban climate model																	🟦	🟦	🟦	🟦	🟦	🟦		
MS4.2	Model results presented to the pilot cities																				🟦	🟦	🟦	🟦	🟦
MS4.3	General information on strategies, measures, risk and costs for tackling UHI in each city																							🟦	
MS4.4	UHI adaptation strategies and action plans complete for each pilot city including indicative costs and taking health risks into account																							🟦	
WP5	**Decision Support and Dissemination**	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
MS5.1	Visualization tool developed													🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
MS5.2	Project website and promotional materials available					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
MS5.3	Conference paper/poster presented													🟦	🟦	🟦						🟦			
MS5.4	Paper submitted to a scientific journal																	🟦					🟦		
MS5.5	Final project event ‘National UHI Workshop’																								🟦

8 Publications and Dissemination Activities

Table 5 contains a list of publications from the ADAPT-UHI project while Table 6 covers a range of dissemination activities including conference presentations and workshops. Dissemination materials produced by the project are outlined in Table 3 and section 4 of this report.

Table 5: List of publications from the ADAPT-UHI project

Title	**Publication**
Using urban climate modelling and improved land use classifications to support climate change adaptation in urban environments: A case study for the city of Klagenfurt, Austria	Published in the journal Urban Climate as an open access paper[1]
Economic valuation of urban heat island mitigation in a small Austrian city	Short conference paper presented at the 3rd International Conference on Green Urbanism (GU), Rome, Italy
Using urban climate modelling to support climate change adaptation in small- to medium-sized cities in Austria	Long conference paper presented at the 3rd International Conference on Green Urbanism (GU), Rome, Italy. To be published in the Springer Advances in Science, Technology & Innovation book series in 2020
A cost-benefit analysis of implementing urban heat island adaptation measures in small and medium-sized cities in Austria	Under review in the journal Environment and Planning B: Urban Analytics and City Science

Table 6: List of presentations of the ADAPT-UHI project at various dissemination events

Dissemination Event	**Title of Presentation**
DACH 2019, Garmisch-Partenkirchen, Germany, 18-22 March 2019 https://www.dach2019.de/ Presenter: Sandro Oswald, ZAMG	Stadtklima-Modellierung zur Anpassung von klein- bis mittelgroßen Städten in Österreich an den Klimawandel
EGU 2019, Vienna, Austria, 7-12 April 2019 https://www.egu2019.eu/ Presenter: Sandro Oswald, ZAMG	Using urban climate modelling to support climate change adaptation in small- to medium-sized cities in Austria
KlimaTag2019, Vienna, Austria, 24-26 April 2019 https://ccca.ac.at/dialogformate/oesterreichischer-klimatag/klimatag-2019 Presenter: Linda See, IIASA	Investigating the urban heat island effect in small- to medium-sized cities in Austria
KlimaTag2020, Leoben, Austria, moved from April to Sep 2020 due to COVID-19	Using urban climate modelling and improved land use classifications to support climate

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[1] Paper available from here: https://www.sciencedirect.com/science/article/pii/S2212095519302846

Dissemination Event	Title of Presentation
	change adaptation in urban environments: A case study for the city of Klagenfurt, Austria **This paper won an award for best paper from a young scientist.**
Urban gardening, Bauwerksbegrüning / Grünraummanagement, Villach, Austria, 27 May 2019 Presenter: Stefan Guggenberger, IPAK	Erfahrungen mit ADAPT-UHI in Klagenfurt
2nd International Conference ADAPTtoCLIMATE, Crete, Greece, 24-25 June 2019 https://conference.adapt2clima.eu/ Presenter: Stefan Guggenberger, IPAK	Using urban climate modelling to support climate change adaptation in small- to medium-sized cities in Austria
Österreichischer Städtebund Klagenfurt, Austria, 24 September 2019 Presenter: Stefan Guggenberger, IPAK	Urbane Hitzeinseln in Klagenfurt – Ergebnisse aus dem Project ADAPT-UHI
Klimawandel in der Stadt. Anpassungsmaßnahmen in Wohnbau, 24 October 2019 Presenter: Stefan Guggenberger, IPAK	Urbane Hitze-Inseln in Klagenfurt – Ergebnisse aus dem Projekt ADAPT-UHI
3rd International Conference on Green Urbanism (GU), Rome, Italy, 11-13 December 2019 https://www.ierek.com/events/green-urbanism-3rd-edition#overview Presenters: Sandro Oswald, ZAMG (Paper 1) and Daniel Johnson, IIASA and ESCP (Paper 2)	Paper 1: Using urban climate modelling to support climate change adaptation in small- to medium-sized cities in Austria **This paper won a bronze award in the best paper category during the conference.** Paper 2: Economic valuation of urban heat island mitigation in a small Austrian city
Final Project Workshop, Klagenfurt, Austria, 5 March 2020	All project results were presented

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