Towards a Green Future with CityCLIM: A Handbook for Interested Cities

Comprehensive information about the general background, benefits for cities, preparation and necessary steps for participation.

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Contribution to Deliverable D1.5 “CityCLIM Framework”

October 2023

Protecting Cities, Preserving Climate
Building Resilient Cities for a Sustainable Future

Foreword

Dear Reader,

In a world where urban populations are expanding and climate change is increasingly impacting urban areas, it's crucial for us to consider how we can bolster our cities to be more resilient in the face of future climate challenges.

CityCLIM offers a step forward towards a greener future. It represents the fusion of innovative climate science, advanced weather modelling, and emerging data sources to help cities adapt to and mitigate the impacts of climate change.

This handbook is a guide for any city that's interested in joining CityCLIM. It's full of useful information about what CityCLIM is, how your city can benefit from it and what you need to join us. It's mainly aimed at city administrators and urban planners, but it's also useful for anyone who's involved in making decisions about a city's future.

But this handbook isn't just a guide - it's also a starting point. It's the first step for anyone who's thinking about to bolster their cities to be more resilient in the face of future climate challenges and their urban impacts. It gives you the information you need to make an informed decision about whether the CityCLIM framework is right for your city.

And if you do decide to join CityCLIM, this handbook will help guide you through the next steps. It's the starting point of a roadmap for your city's journey towards a greener, more sustainable future which comes with several tools for cities to use as they navigate the challenges of the future. We hope you'll join us on this exciting journey.

Sincerely,

The CityCLIM Consortium

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1 Why CityCLIM?

1.1 What is CityCLIM?

CityCLIM is a project funded by the European Union. Its goal has been to create an open platform of Climate information and mitigation services utilising various sources like Earth observation data and a detailed urban weather prediction model. This model will provide detailed weather predictions for various cities in Europe, drawing information from ground measurements, airborne and satellite data. The project recognizes the strong impact of climate change on urban life, including factors like living conditions and quality of life. Therefore, our model looks at challenges like prolonged heat or air pollution. Understanding the spread of heat stress in different urban areas, such as city centers, residential zones, and parks, is crucial for both city planning concerning climate change and daily individual decisions.

The high-quality information from this prediction tool will offer near-instant warnings to cities and their residents. It will also create maps showing the effects of potential solutions for city challenges. The GCCP, or CityCLIM service platform, will give useful information to tackle the issues of climate change for city administrations or city planners. It will engage the public and decision-makers from the start, offering City Climate Services (CCS) through an easy-to-use frontend and via modern API access. The project has been seeking to introduce new services that help residents and city leaders identify possible future challenges, allowing them to address these problems early. It hereby provides a first framework on how other interested cities can participate and get to use the CityCLIM solutions.

As such CityCLIM provides a framework that can be adapted by other interested cities to strengthen their own climate change adaptation and mitigation strategies.

Figure 1: Landing page of CityCLIM.eu to gain more information about the CityCLIM project.

The CityCLIM project has six consortium partners and four participating pilot cities that have worked together to conceptualize, develop and test the new climate services that are the main objectives of the CityCLIM project. The resulting framework delivers technologically advanced City Climate Services (CCS) for citizens and city administrations to cope with urban heat islands and can be adapted by any interested region or city.

1.2 What are Urban Heat Island Effects?

The Urban Heat Island (UHI) effect is a prominent environmental issue, predominantly found in heavily populated and industrialized metropolitan areas. This phenomenon is characterized by elevated temperatures within urban environments as opposed to their suburban or rural counterparts, primarily due to human-made alterations to the landscape and the utilization of materials with high thermal absorption. Urban constructs like buildings, roadways, and other infrastructural elements absorb and subsequently reemit more of the sun's heat compared to natural landscapes such as forests and water bodies, which leads to an accumulation of heat. This difference in holding heat leads to a noticeable rise in city temperatures.

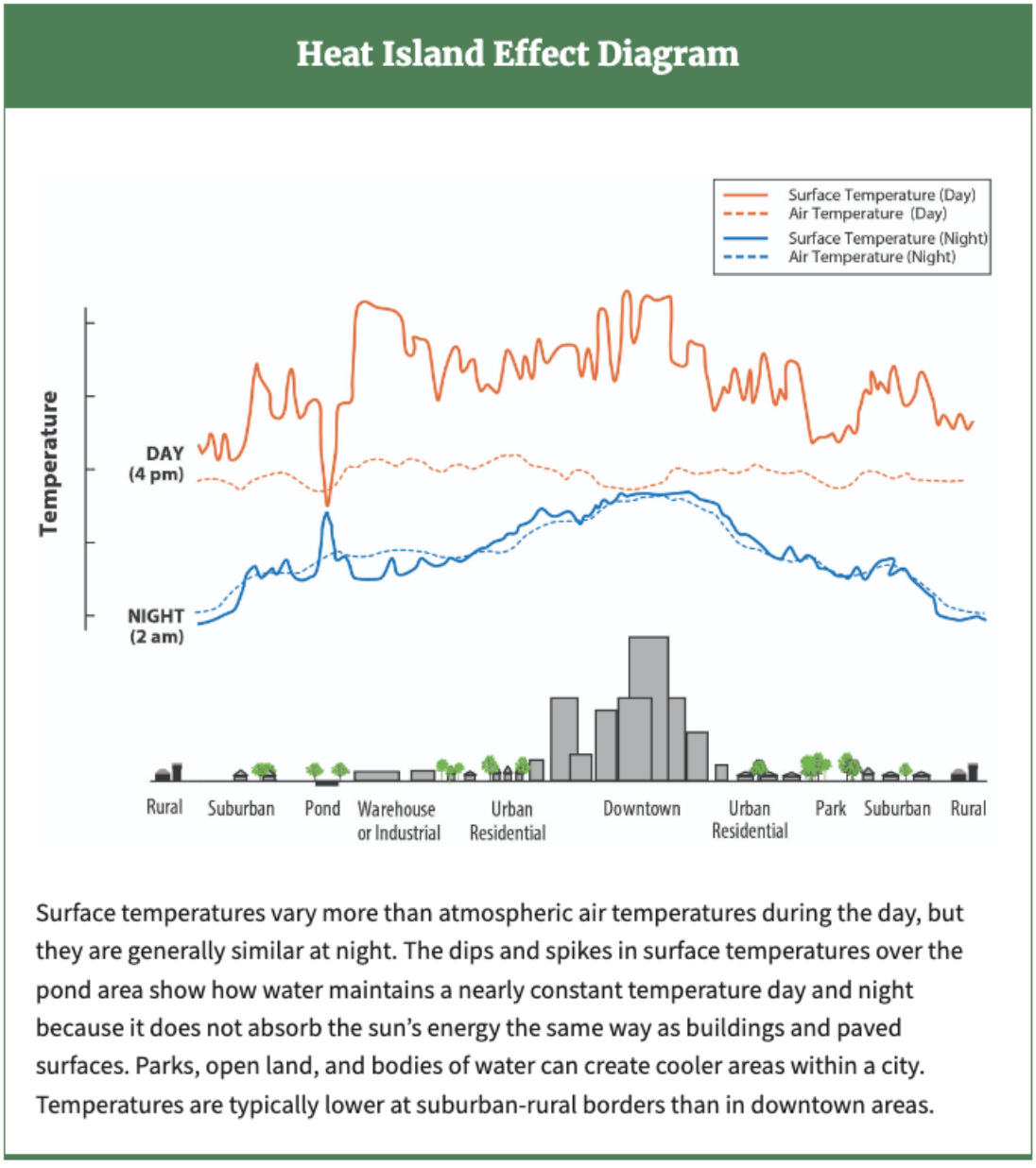

Figure 2: Graphic depicts Urban Heat Island Effects, source: https://www.epa.gov/heatislands/learn-about-heat-islands

Additionally, the extra heat produced by cars, factories, and air conditioning units worsens that temperature rise even more. This increase in heat can significantly change local weather patterns, making heatwaves more common, longer, and more severe, causing a range of problems that affect both society and the environment. These problems include health troubles, the need for more energy, and lower quality of water. In simple terms, UHI is a complicated problem that links changes in the environment, buildings in the city, and impacts on nature. It requires careful consideration and well-planned actions to improve and sustain life in cities.

1.2.1 How do Urban Heat Islands interact with climate change?

The effects of Urban Heat Islands (UHIs) are interlinked with climate change in several ways. Urban Heat Islands are formed when urban areas experience higher temperatures compared to their rural surroundings due to human activities, modifications to land surfaces, and waste heat from energy usage. These elevated temperatures, in turn, contribute to the overall warming trends observed in climate change. Here's how UHIs and climate change are interconnected, with emphasis on evidence particularly in Europe:

- **Elevated Temperatures:** UHIs contribute to local temperature increases, intensifying the effects of global climate change by raising baseline temperature levels in urban areas. In Europe, cities like Paris, London, Athens, Madrid, Rome, and Berlin have all experienced the impacts of UHIs, with heatwaves in 2003 and 2019 serving as notable examples of these elevated temperature levels contributing to record-breaking temperatures and resultant fatalities across the continent.
- **Alteration of Local Climate Patterns:** UHIs can also alter local weather patterns, potentially affecting precipitation and cloud cover patterns in and around urban areas. The modification of land surfaces and the increased heat can lead to localized changes in atmospheric circulation, further contributing to climate variability in those regions.

Figure 3: People protesting demanding political action on climate change.

The increased use of fossil fuel energy in urban areas for transportation, industrial activities, and building operations leads to higher emissions of CO2 and other greenhouse gases, contributing to global climate change.

Numerous studies and climate models indicate an increasing trend in the frequency, duration, and intensity of heatwaves in European cities, attributed to the synergistic effects of UHIs and climate change. European cities, due to their dense built environment and extensive industrial activities, have been a focal point for studying the impacts of UHIs. The increased temperatures and altered climatic patterns observed in these urban areas are indicative of the intertwining impacts of UHIs and climate change. The environmental impacts observed in European urban areas, such as changes in local ecosystems and weather patterns and increased pollution levels, are also indicative of the link between UHIs and climate change.

Addressing the synergy between UHIs and climate change is crucial in mitigating the impacts of rising global temperatures, especially in densely populated urban areas across Europe, to foster sustainable urban development and protect human and environmental health.

1.2.2 What are the causes of Urban Heat Island Effects?

Heat islands are created when a few different things come together in cities and towns, leading to higher temperatures in these areas.

- **Changed land use:** Firstly, in cities, there are fewer natural landscapes like trees, plants, and water bodies that usually cool down the air by providing shade and evaporating water. Instead, there are many hard, dry surfaces such as buildings, roads, and sidewalks that don't give much shade or moisture, making cities hotter. Secondly, the materials used to build in cities, like for example roads and roofs, usually hold and give off more of the sun's heat compared to natural surfaces. The heat from these materials builds up during the day and is slowly released even after the sun sets, making the heat island effect more noticeable.

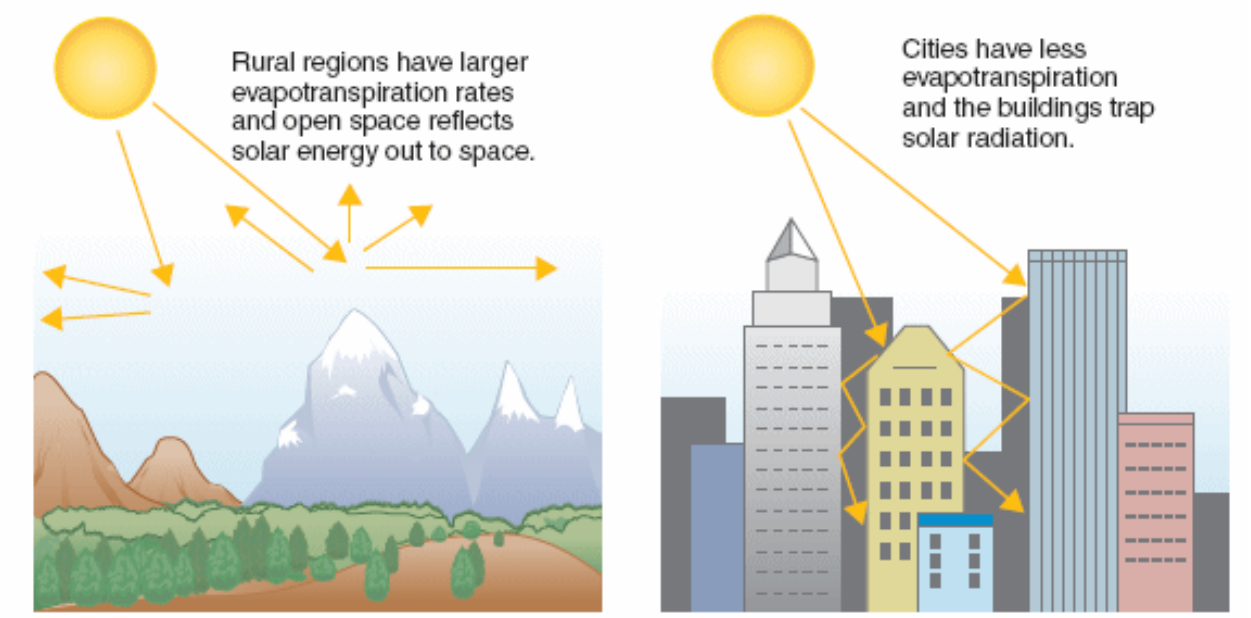

Figure 4: Radiation differences resulting in Urban Heat Island effects. Source: https://cimss.ssec.wisc.edu/climatechange/globalCC/lesson7/UHI2.html

- **Materials:** Another key reason behind the formation of heat islands is the specific characteristics of materials used in cities. The main materials used in city buildings and roads, like concrete and asphalt, usually absorb and give off more heat and reflect less sunlight compared to natural surfaces like plants. The heat stored in these materials gets stronger as the day goes on and stays long after the sun has gone down, due to the slow release of heat from these city structures.
- **City planning and urban geometry:** The way buildings are arranged in a city, known as urban geometry, also affects how hot it can get. In areas with lots of tall buildings and narrow streets, the buildings block the wind and trap heat, acting like big heat-holding masses. This setup can block the cooling effect that natural wind flow would typically bring. Additionally, heat is also emitted from everyday human activities like driving, using air conditioners, and running industrial facilities, contributing to the overall heat in the urban environment.
- **Local weather & climate change**: Lastly, the weather and geographical features of a place also play a role. When the weather is calm and clear, more sunlight reaches urban surfaces, and less heat can be carried away, intensifying the heat islands. On the other hand, strong winds and clouds can reduce the heat island effect. Even the geographical features around a city, like mountains, can either block or channel wind into a city, affecting how hot it can get. In simpler terms, all these factors combined make urban areas much warmer, creating what is known as heat islands. Climate change and its increasing global

average temperatures, result in more frequent, prolonged, and intense heatwaves. This is largely due to the accumulation of greenhouse gases in the atmosphere, trapping more heat and leading to a warmer planet.

1.2.3 Why are Urban Heat Islands a problem for Cities?

The lack of green spaces, combined with densely packed buildings and narrow streets, contributed to extreme temperature elevations, causing substantial public health concerns.

In Europe, Urban Heat Islands (UHI) have been observed in several cities such as Paris, London, Athens, Madrid, Rome, and Berlin. The 2003 European heat wave was one of the deadliest natural disasters that caused an estimated 70,000 deaths across Europe. The heat wave was particularly severe in France: In Paris alone, the temperature rose above 37°C for seven consecutive days. The city's infrastructure was not designed to handle such extreme temperatures leading to a surge in hospitalizations due to heat-related illnesses. Because of that, many European cities like Paris, have been implementing mitigation strategies towards UHI related effects, such as increasing green spaces and green roofs, enhancing urban planning to incorporate more reflective materials, and improving early warning systems and public awareness to reduce the impact of UHI on public health.

The European heat wave in 2019 was another example of how urban heat islands can affect public health. France recorded its highest-ever temperature of 46°C during this event (28th of June in Vérargues, Hérault). It again caused several deaths across Europe due to dehydration and other heat-related illnesses. Also in Greece, the country of one of our pilot regions: The Region of Central Macedonia and Thessaloniki, a heat wave struck in 2021 with temperatures up to 47°C.

1.2.3.1 Compromised Human Health and Comfort

Urban Heat Islands (UHI) are significant contributors to elevated daytime temperatures, a reduction in cooling during the nighttime, and heightened levels of air pollution within urban environments. These phenomena lead to a range of adverse health effects, impacting both the comfort and well-being of urban citizen. The presence of increased temperatures and elevated pollution levels associated with Urban Heat Islands is called heat stress.

Figure 5: Elderly woman struggling under heat stress.

This heat stress is closely linked with other heat-related illnesses such as heat exhaustion and heat stroke, which are of significant concern in areas affected by elevated temperatures. The increased temperatures prevalent in Urban Heat Islands can disrupt the human body's ability to cool itself effectively. This disruption can lead to severe health consequences, including dehydration and electrolyte imbalance. When these conditions are left unaddressed, they can escalate to more serious complications like organ failure, which can be fatal. The spectrum of heat-related illnesses includes, but is not limited to, general discomfort, respiratory difficulties, heat cramps, and heat exhaustion, with non-fatal heat stroke also being a notable concern.

In places with higher temperatures, some people are more at risk. The elderly, children, and those with existing health problems are more likely to feel the bad effects of the heat and dirty air caused by Urban Heat Islands. These groups are more likely to get sick from the heat, especially in big cities where the hot and polluted conditions are the worst.

To sum it up, Urban Heat Islands make cities hotter, causing more heat at day and at night and more air pollution. This can lead to health problems, like heat sickness or even death, especially for high-risk groups like the elderly, children, and people with health issues. When it's too hot, our bodies can't cool down well, which can be dangerous. This shows why it's important to think about Urban Heat Islands when planning cities and making health rules.

1.2.3.2 UHI Causes an Increased Energy Consumption:

Urban Heat Islands make areas hotter, causing a higher need for energy, especially for air conditioning, to cool down buildings. This means people in these hotter areas use more air conditioning, which leads to more electricity being used and higher bills for those people. Additionally, these hot spots not only increase the usual electricity usage but also the highest usage levels during certain times. Energy companies pay special attention to these high-usage moments because it's the most stress on their system. So, when there are Heat Islands, even more energy is used during very hot events.

If too many people use electricity at the same time, it can stress out the system. To prevent the whole system from shutting down, energy companies might reduce power locally, called brownouts, or even turn off the power, known as blackouts. This can be a big problem for communities, especially when it's very hot.

In short, Heat Islands make people use more energy, which can raise their electricity bills and put a lot of pressure on our power systems. There might be times when energy companies have to cut power to keep everything balanced. This shows how Heat Islands can really affect our energy use and how we manage it.

1.2.3.3 UHI Cause Elevated Emissions of Air Pollutants and Greenhouse Gases

Heat islands significantly heighten the demand for electricity, especially during the summer months when the temperature is typically higher. The increased need for electricity during these times is mostly handled by electricity supply companies. These companies often rely a lot on power plants that use fossil fuels to meet the higher demand. Using more electricity often means burning more fossil fuels, which is bad for the environment.

This can cause more air pollution and increase greenhouse gases. The pollution from burning fossil fuels is harmful to both people and the planet.

This pollution isn't just bad for our health directly, but it also adds to the air quality problems that hot areas already face, as they contribute to the formation of ground-level ozone, fine particulate matter, and acid rain. Breathing in polluted air can cause lung problems and other health issues for people besides detrimental environmental effects.

Additionally, the emissions contribute to the formation of acid rain, a phenomenon where precipitation contains elevated levels of acidic components due to the presence of atmospheric pollutants. Acid rain can have widespread environmental impacts, affecting soil, water bodies, and ecosystems, thereby further worsening the environmental impact of elevated emissions associated with heat islands. In summary, the presence of heat islands escalates the demand for electricity, predominantly during the warmer summer months, and in addition entails multifaceted environmental and health impacts.

Figure 6: Nuclear power plant chimney and castle in Cofrentes. Valencia, Spain

The heightened electricity demand is currently still largely met by fossil fuel-powered plants, leading to increased emissions of air pollutants and greenhouse gases. These emissions are detrimental to human health, contributing to the formation of ground-level ozone, fine particulate matter, and acid rain, each posing distinct challenges to air quality and environmental health. These complexities highlight the multifaceted environmental and health impacts arising from the increased energy consumption in areas affected by heat islands.

2 How can CityCLIM help you become a climate-resilient city?

As the causes as well as the effects of climate change and Urban Heat Islands on cities are manifold, an appropriate answer to such complex problems cannot be a single one. Hence, the CityCLIM consortium identified several needs addressing different stakeholders within a region or city that wants to use the CityCLIM framework for its citizen.

To better understand, how CityCLIM can support your city in its efforts, it is crucial to understand, what kind of solutions and strategies have been discovered in the literature to be successful.

2.1 Mitigation & Adaptation strategies tackling Urban Heat Island Effects

- ✓ **Increasing green spaces:** Planting trees and other vegetation in urban areas can help to reduce the UHI effect by providing shade and evaporative cooling. Green roofs and walls can also help to reduce the UHI effect by providing insulation and reducing heat absorption.
- ✓ **Using cool roofs and pavements:** Cool roofs and pavements reflect more sunlight than traditional roofs and pavements, reducing the amount of heat absorbed by buildings and streets. Reflective coatings, tiles, or shingles can be used to make roofs cool, while reflective concrete or asphalt can be used for pavements.
- ✓ **Improving building design:** Building design can be optimized to reduce heat absorption and improve ventilation. For example, buildings can be oriented to reduce solar exposure, windows can be shaded, and natural ventilation systems can be installed.
- ✓ **Using water bodies:** Water bodies such as lakes, ponds, and fountains can help reduce the UHI effect by providing evaporative cooling.
- ✓ **District-level cooling:** District-level cooling that efficiently uses energy to mechanically cool large areas in cities can help reduce heat impacts.
- ✓ **Promoting energy efficiency:** Energy-efficient appliances and lighting systems can help reduce the amount of heat generated by buildings.
- ✓ **Implementing nature-based solutions:** Nature-based solutions are scalable and affordable interventions for climate resilience. The strategic reintroduction of nature can lower temperatures, improve air quality, and at the same time enhance biodiversity. In cities, the increase of tree canopy cover has proven to reduce heat-related mortality, as shown by a recent study in the Lancet of European cities increasing city tree coverage to 30%, could have prevented 2,644 excess deaths.
- ✓ **Integrated, Inclusive planning:** Integrated, inclusive planning of urban stakeholders to ensure that vulnerable urban residents are protected can help reduce heat impacts.
- ✓ **Knowledge and information:** Gaining insights into the knowledge of resilience and adaptation against adverse urban heat effects contribute to the development of sustainable cities.
- ✓ **Warnings:** Providing timely and reliable warnings of upcoming heat events can protect populations that are especially vulnerable to heat. These warnings need to be precise to be of value as otherwise adherence is low.
- ✓ **Engagement of citizen:** The United Nations Framework Convention on Climate Change (UNFCCC) states that getting the public involved is crucial for tackling climate change. When people are involved, they learn more about the problem, promote sustainable practices, and push their governments to act. This also helps to see and help communities that are hit hardest by climate change.

2.2 The CityCLIM Service Framework

To cover the identified areas of interest the CityCLIM project aimed to provide two sets of mitigation and adaptation services to tackle Urban Heat Island effects and other climate change related hazards. These two sets are targeting different stakeholders within a city: the general public and decision makers within each region.

All services are provided via a modern SaaS-solution: the Generic City Climate Platform (GCCP). This platform collects all input data for the service provision, unifies and postprocesses them, and provides a variety of so-called “Engines” that generate the relevant output from the weather model and other service components. However, the GCCP is not only a sheer data collection and processing tool, it also provides a user-centred frontend that allows its subscribers to access all services visually via an intuitive dashboard. Furthermore, the GCCP provides API endpoints for all participating cities, so that the output of some services (e.g., the Citizen Climate Knowledge Services) can be also accessed directly and each city can decide individually on how to display or integrate these services on their own public outlets for their citizen.

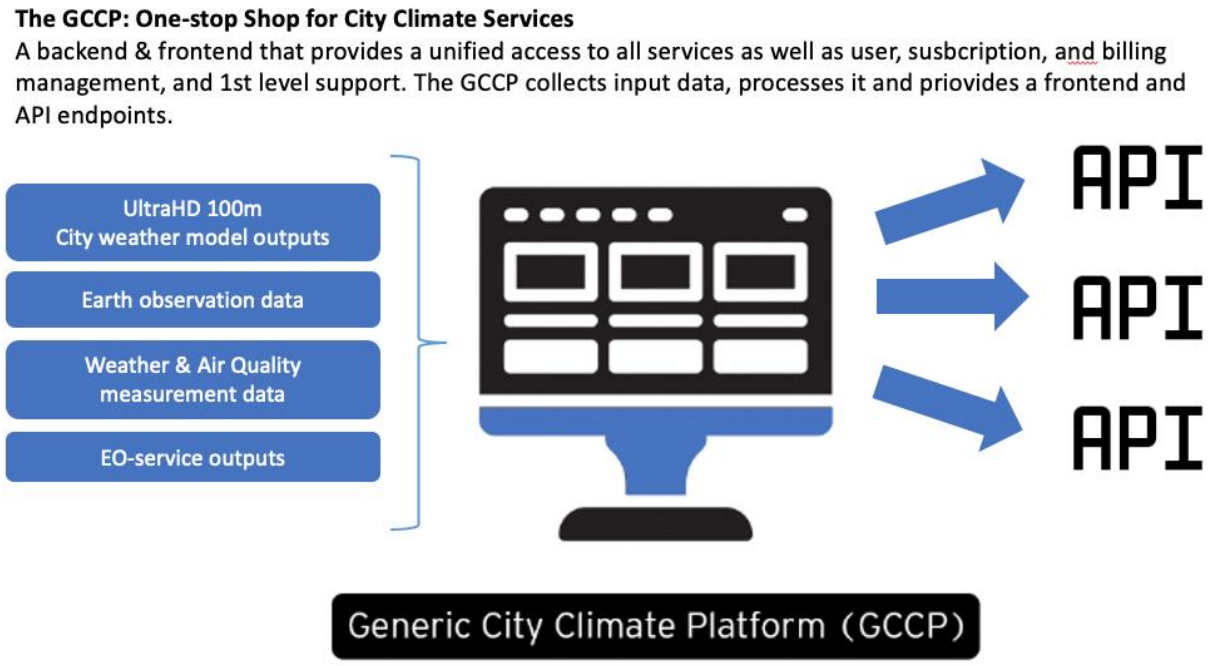

Figure 7: A schematic representation of the Generic City Climate Platform.

1. Citizen Climate Knowledge Services: Within the Citizen Climate Knowledge Services (CCKS), the CityCLIM solution provides specialized services focused on **1) informing citizens** regarding their immediate urban environments and fostering an understanding of shifting climate conditions both within and beyond their local urban surroundings. They are also intended to **2) warn citizens** from upcoming severe heat waves (and potentially other weather hazards).The goal of CCKS is finally **3) to engage and support people** learning about weather and climate happenings in their city areas and to spark interest and knowledge about climate change and how it affects these areas.

The CCKS are supposed to be public, aiming to enlighten and engage citizens from varied locations, even those residing outside the participating cities. The services also aim to provide a unified approach to motivate people to get involved and learn more about how to adapt to climate change.

In short, Citizen Climate Knowledge Services are designed to:

- ✓ Inform citizens about climate change
- ✓ Warn citizens timely and precisely about impeding hazards related to climate change
- ✓ Engage citizens in taking action to mitigate and adapt to climate change

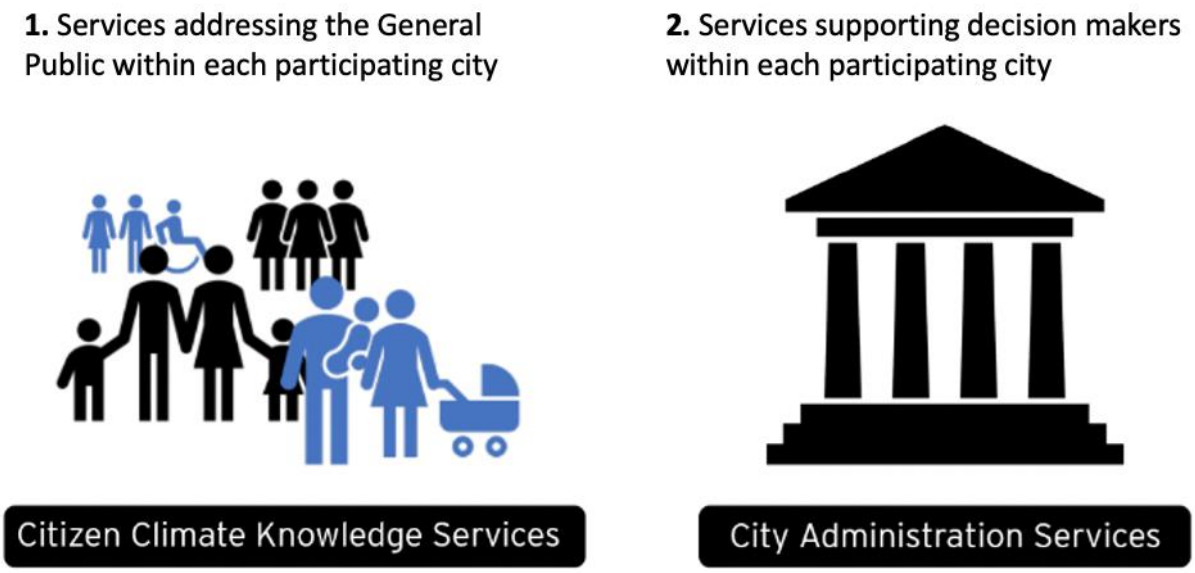

Figure 8: Overview over general service categories provided by the CityCLIM framework.

2. City Administration Services: The City Administration Services aim to assist users in exploring different aspects of city climate profiles, focusing predominantly on understanding and modifying urban climate elements like heat islands, pollution, and city air flow. These services provide an intricate combination of identification, simulation, and mitigation solutions, available through web-based graphical user interfaces (GUIs), facilitating users to investigate and simulate alterations to urban areas and their potential impacts on the climate. The City Administration services are provided for people in decision making positions regarding **a) city planning, b) mitigation and adaption strategies against climate change** and **c) other decision-making stakeholders involved** in the planning and maintaining of climate-resilient city infrastructure and policies.

In short, the City Administration Services are designed to:

- ✓ Support sustainable city planning
- ✓ Simulate evidence-based local scenarios for climate change adaption and mitigation activities
- ✓ Provide a meaningful decision-aid for stakeholders in regard to how certain actions would impact a city's microclimate.

2.3 The heart of CityCLIM: The Urban Weather Model (UltraHD)

How does CityCLIM build these services?

The UltraHD is an urban weather forecasting model designed to operate at an ultra-high resolution of 100 meters. It is focused on addressing the complexities and specialties of urban environments. It differs from usual studies and projects that usually employ moderate model resolutions and subsequently downscale them.

The UltraHD model aims to:

- ✓ **Understand** the challenges posed by climate change effects within urban areas, especially potential problematic zones.
- ✓ **Offer detailed insights** into wind patterns, turbulence, temperature, and other meteorological processes at the micro level.
- ✓ **Assist cities** in adjusting their structural planning based on detailed weather forecasting insights.
- ✓ **Serve as a basis** for further development and enhancements to better understand city-scale weather and air quality processes impacting urban life.

The general UltraHD processing chain

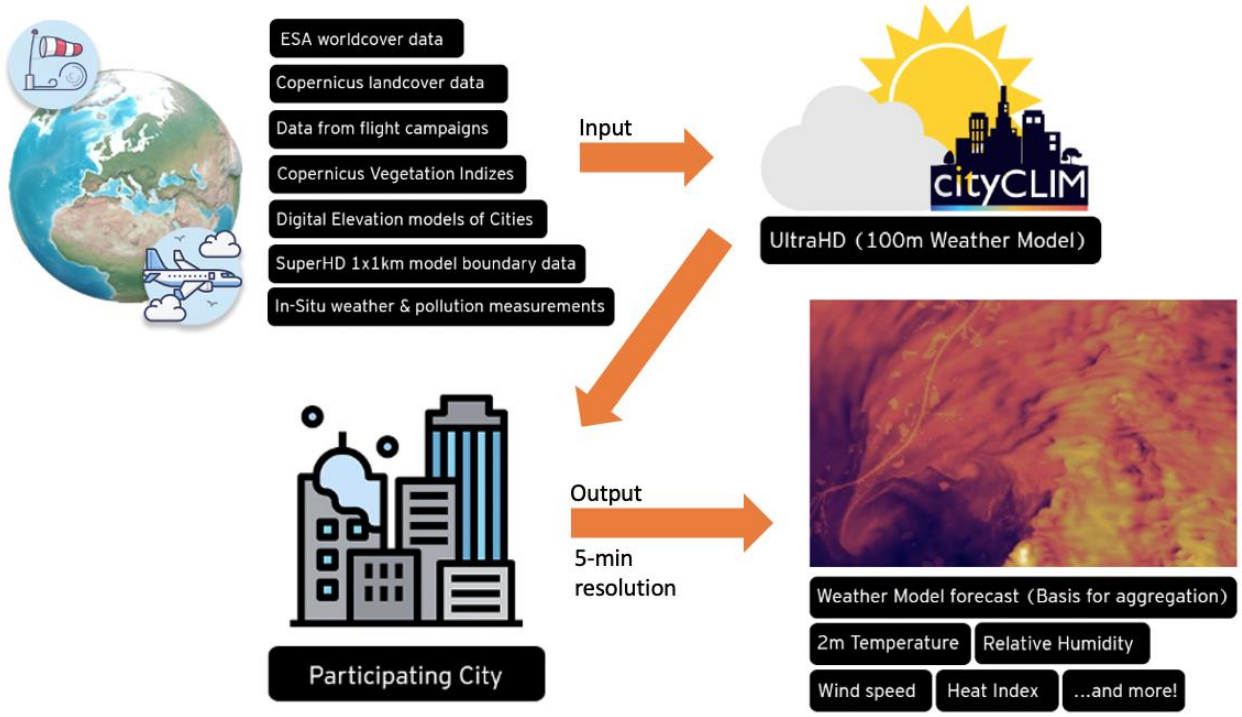

Figure 9: The UltraHD receives a plethora of input data from earth observation services as well as in-situ data and boundary data from the SuperHD 1x1km model and is then applied to a Pilot city. It produces a variety of relevant weather forecast parameters.

How does the UltraHD weather model work?

- ✓ Utilizes a fine mesh size of about 100 m, which allows for better data assimilation, especially from weather sensors (mobile and stationary).
- ✓ Built on a foundation provided by Meteologix AG's expertise in weather modelling and atmospheric process prediction.
- ✓ Nested within the larger 1x1 km SuperHD model, it inherits boundary data and refines it for high precision local analysis.
- ✓ Relies on high-quality input data like topography, building heights, vegetation type, and more (Copernicus data, other satellite and Earth observational data, 3D city models, etc.)
- ✓ Outputs data for various prognostic variables, such as wind speed, temperature, humidity, precipitation, and more.
- ✓ Has potential applications in modelling air pollution as done for pilot city Valencia
- ✓ Uses high-resolution maps for temperature forecasts, local heat indices, pollution forecasts, and risk of increased pollution.

As such, the UltraHD is able to:

- ✓ Create individual high-resolution **short-term weather forecasts** of up to 2 days for a city or region.
- ✓ It can be used to create highly **accurate weather warnings** and visual weather forecasting maps
- ✓ Its data can be saved and aggregated to **discover patterns** (regarding general air flow, heat accumulation, particle accumulation and so on).
- ✓ Past runs can be used to **simulate changed conditions** (scenarios like changes in land use, etc.) to test potential mitigation strategies (like adding green spaces, nature-based solutions, etc.)

Within the CityCLIM project, the UltraHD model has been expanded to forecast additional parameters such as soil moisture, plant parameters, heat stress, and pollution forecasts. The goal was to assimilate more external datasets and upgrade its databases, transforming it into a robust tool for predicting and diagnosing urban challenges anticipated due to climate change.

As such, the UltraHD is an invaluable tool for urban planners, environmentalists, and policymakers, offering precise forecasts that can help cities prepare for and combat the challenges of climate change. It has also been developed to be integrated in existing SMART city solutions and to be run operationally over long periods of time in order to build a database of analysis data over time that can be aggregated and explored further.

2.4 The Citizen Climate Knowledge Services

The Citizen Climate Knowledge Services are services available to the public, created for curious citizens both within and outside of the pilot cities. Their purpose is to increase understanding and awareness of weather and climate dynamics in urban settings but also to warn citizen about upcoming potential weather hazards. Additionally, the services encourage citizens to participate in possible adaptation approaches and expand their knowledge regarding the effects of climate change on cityscapes.

As such, Citizen Climate Knowledge Services seek to inform, warn and engage the citizens of a participating city. We have built a suite of such services comprising of:

- ✓ **Climate Information Services:** These services aim to grant access to extensive databases and computational engines which offer both contemporary and historical data measurements along with enriched data derivatives. The purpose is to facilitate open-access examination and visualization of data in various forms, accommodating a broad spectrum of interests. This service is generally open under meteologix.com and information for each pilot city can be accessed via the Meteologix.com frontend or provided as an iframe or web widget solution for the participating city's website.
- ✓ **Heat Wave Information Service:** This service will be instrumental in overseeing present or imminent heatwaves and pinpointing areas that are severely affected. It is envisioned to assist individuals in modifying their activity schedules and mitigating the stress experienced due to heat.
- ✓ **Warning Service:** This service creates maps (or messages) that show weather warnings and discourage citizens from visiting certain affected areas. Within the initial project this service has been applied to the Heat Wave Information Service, but warnings can be generated for any meaningful weather parameter.
- ✓ **Pollution Information Service:** This service intends to deliver insights regarding prevailing pollution levels and prospective conditions in subsequent days, incorporating model analyses of actual measurements and brief pollution projections for selected pilot cities.
- ✓ **Citizen Weather Sensation Map:** This service is developed to convey subjective weather experiences of citizens to provide diverse perspectives on weather conditions.

2.4.1 Climate Information Services

Through the Meteologix portal, the Climate Information Services presents extensive climate details, such as temperature, humidity, and rainfall records. The platform, user-centric in design, promotes active engagement by presenting data in an accessible manner. As part of the MTL's meteologix.com system, there's an ongoing effort to amass more data from both exclusive and open sources.

Additionally, users have the possibility to contrast data from different stations and undertake elementary statistical tasks like trend analysis. As such, the climate services grant its users access to vast databases and tools showcasing both contemporary and historical data in various formats. These services, tailored for diverse interests, can be reached at meteologix.com with specific information for each pilot city present on the Meteologix.com platform. Cities may also have the option to incorporate it into their websites using iframe or web widgets.

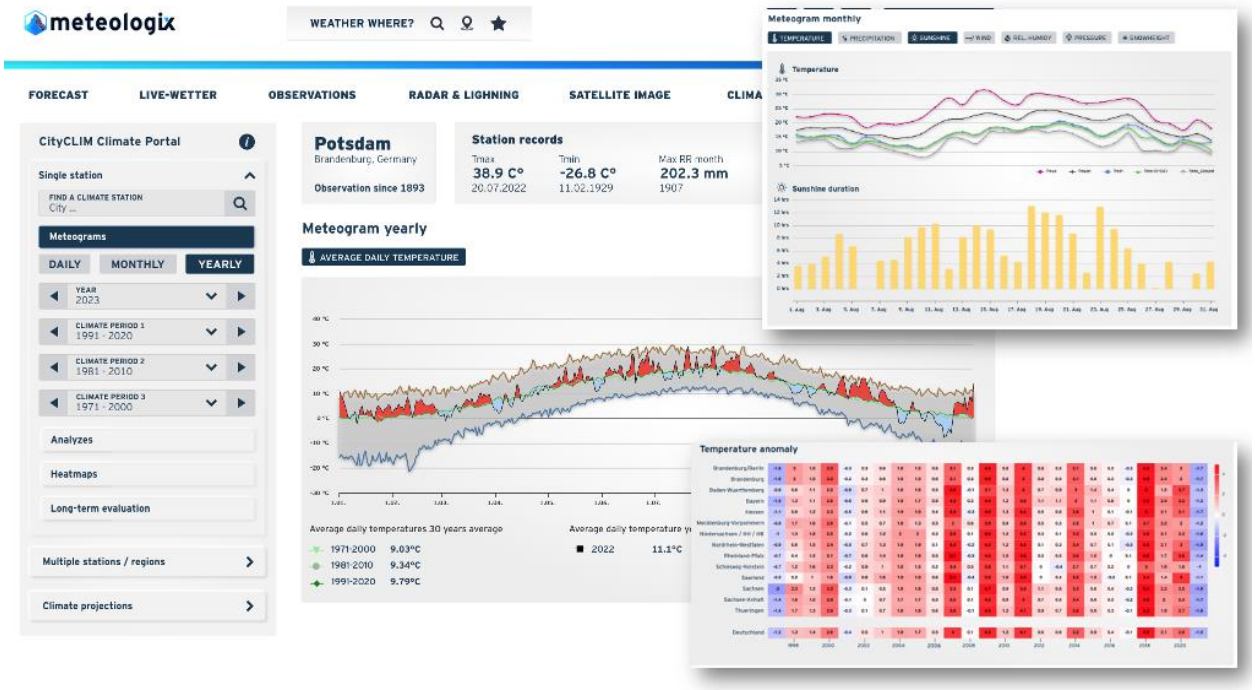

Figure 10: Screenshot of Meteologix.com - The weather website with the climate (historic weather) information for international weather stations

Fact Box 1: CityCLIM Climate Information Service

- ✓ Informs citizen about local climatic condition
- ✓ Provides educational context
- ✓ Engages citizen in exploring local weather conditions and climate
- ✓ Might motivate citizens in tolerating climate friendly policies and actions

2.4.2 Heat Wave Information Service

The Heat Wave Information and Warning Service aims to share details right before and during a heat wave, mainly for curious residents in specific city areas. It uses the UltraHD city weather model and real-time measurements. Its outputs are shown using maps and charts. The service has two parts:

- ✓ An analysis that shows the current heat and moisture in the city using past model results and recent measurements.
- ✓ A prediction of upcoming weather, like temperature, humidity, and the Heat Index

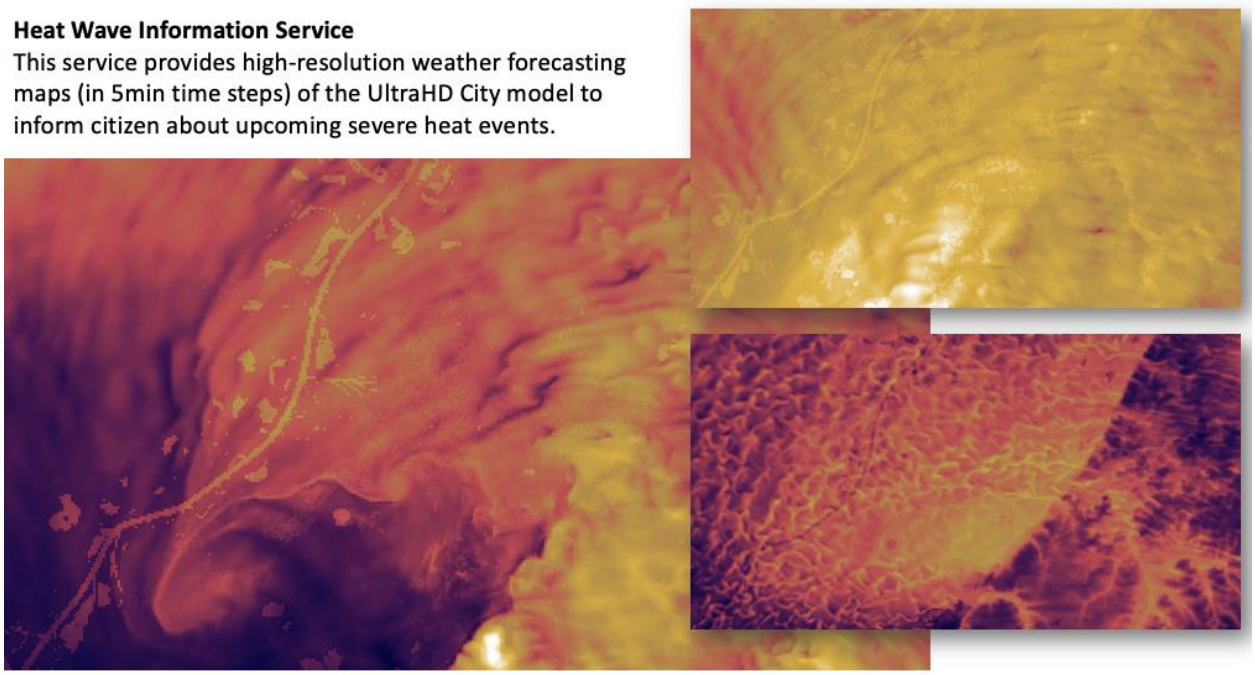

Figure 11: An UltraHD city weather model air temperature forecast map. This map can be accessed via the GCCP or can be integrated in a proprietary city solution via API endpoint or web widget.

Fact Box 2: CityCLIM Heat Wave Information Service

- ✓ Informs citizens about upcoming heat waves
- ✓ Aids users in planning activities
- ✓ Engages citizens in exploring local weather conditions and climate
- ✓ Creates trust in local authorities

2.4.3 Warning Service

The Weather Warning Service is designed to provide clear and immediate insights into potential weather risks using a colorized map. Adopting a user-friendly traffic light pattern, the map displays areas based on the level of risk. Specific thresholds, which are yet to be determined, will categorize regions into three main categories: no warning, medium warning, and high risk. This visual representation allows residents to quickly understand and assess the severity of the upcoming weather conditions in their area, promoting better preparedness and safety measures.

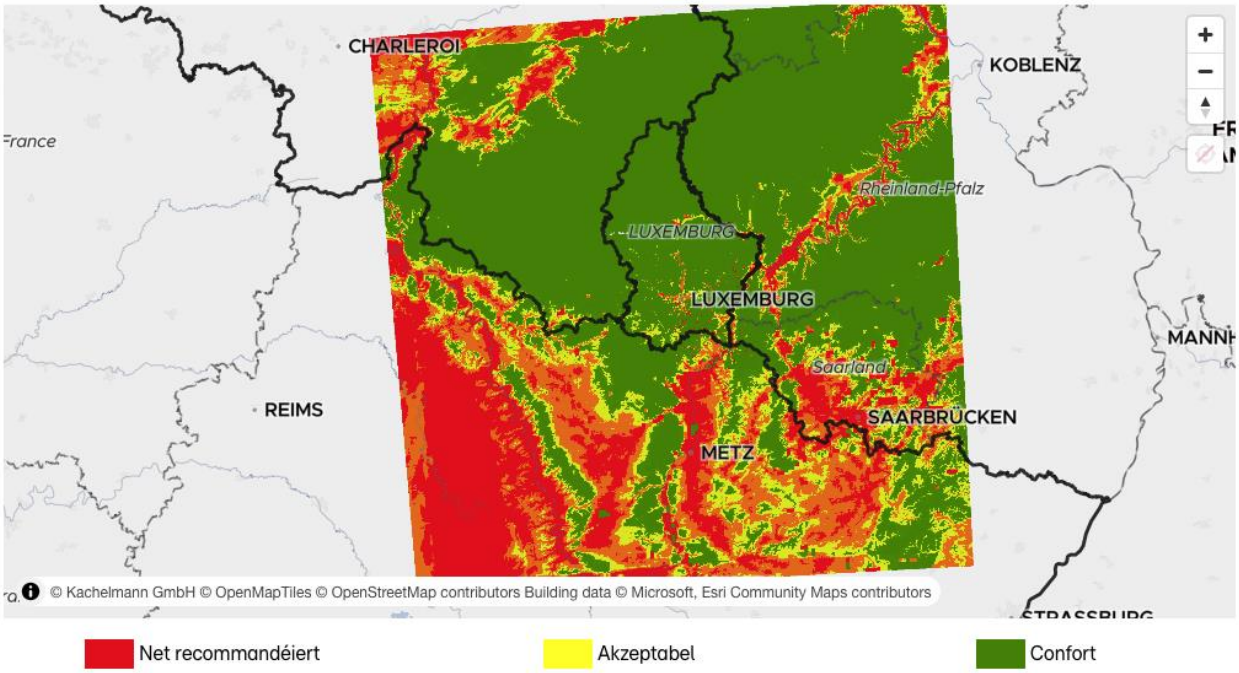

Figure 12: Example of a weather warning map.

Fact Box 3: CityCLIM Warning Service

- ✓ Informs citizens about potential weather hazards
- ✓ Aids users in planning activities
- ✓ Engages citizens in exploring local weather conditions
- ✓ Creates trust in local authorities

2.4.4 Pollution Information Service

The pollution information service is similar to the Heat Wave Info Service, but it focuses on pollution details. It uses more detailed calculations in its UltraHD model, which requires more computing power and specific input data.

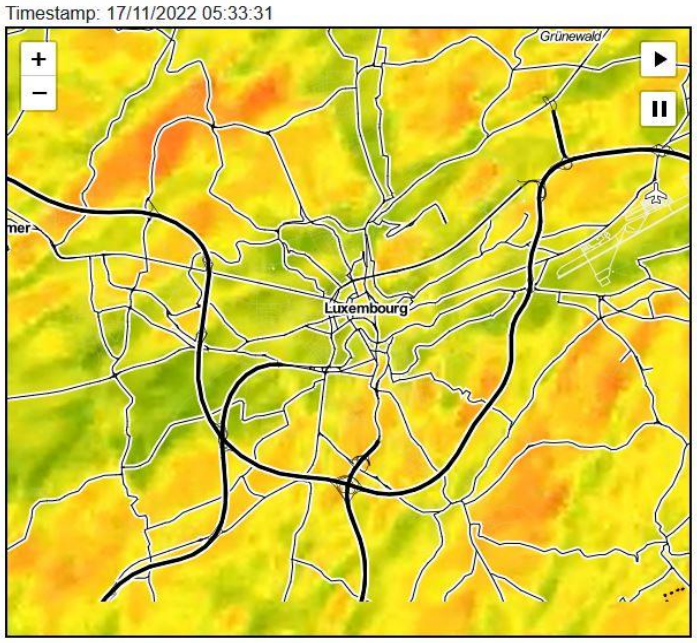

Figure 13: Example of Pollution Information Service Map.

In order to subscribe to this service, a participating city needs to either already have an existing air quality measurement network in place or to install air quality sensors throughout the city together with the support of the CityCLIM team.

This service will show information on air pollution, like tiny dust particles (PM10, PM2.5) and certain gases (NOx, O3). It uses both SuperHD and UltraHD models, along with on-the-spot measurements, to show the current pollution levels in the city and predict future levels.

However, the forecasts might be shorter because of the detailed calculations needed. Another feature of this service is the "Urban Pollution Index". This index shows how likely the weather is to trap pollution close to the ground. It uses weather details like wind speed to figure this out. Output maps are similar to the ones in the Heat wave Information Service.

Fact Box 4: CityCLIM Pollution Information Service

- ✓ Informs citizen about potential air quality hazards
- ✓ Aids users in planning activities
- ✓ Engages citizen in exploring local weather conditions
- ✓ Supports city planning activities

2.4.5 Citizen Weather Sensation Map

The City Weather Sensation Map is a tailored weather map that factors in the Heat Index (HI) and allows users to select their "comfort temperature range," considering both air temperature and humidity. This provides a clearer understanding of the perceived temperature for an individual. The map aims to assist in planning activities, with colors indicating comfort levels: green being ideal and red suggesting avoidance. Users can adjust their comfort preferences, and the map, part of the “Citizen Weather Sensation Service,” is generated based on these settings, helping users decide their activities and locations accordingly.

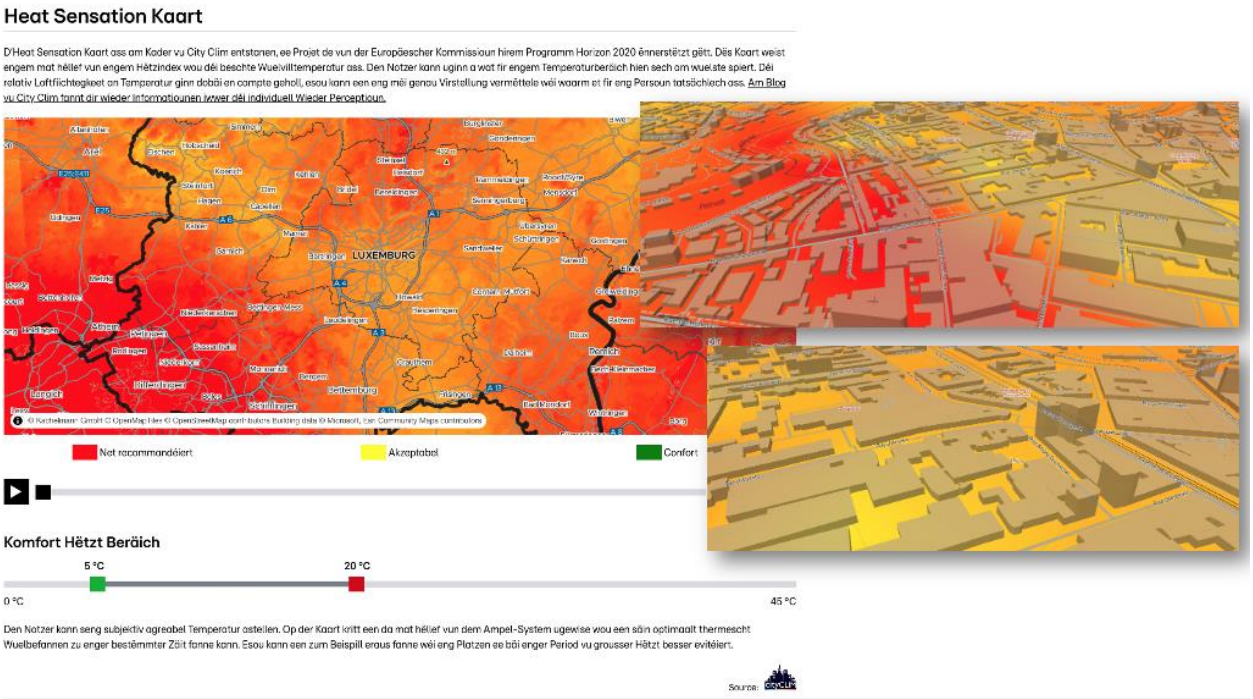

Figure 14: Citizen Weather Sensation Map: a tool to engage citizen to explore how heat accumulates and how they can adapt by knowing which places to avoid and when.

Fact Box 5: CityCLIM Citizen Weather Sensation Map

- ✓ The City Weather Sensation Map is a personalized weather tool using color codes, like green for ideal conditions and red for uncomfortable ones, to indicate suitability for outdoor activities.
- ✓ Aids users in planning activities based on their comfort preferences.
- ✓ Engages citizen in exploring local weather conditions
- ✓ Prevention of heat related hazards

2.5 The City Administration Services

The City Administration Services are divided in identification and simulation applications.

The **Identification Services** enable users to perform statistical analysis on aggregated climate-related data drawn from the CityCLIM ecosystem. These services include the Heat Island Identification Service, the UltraHD-based City Air Flow Identification Service, and the UltraHD-based Pollution Area Identification Service. Each service is equipped with a graphical interface allowing users to analyze urban areas regarding different environmental parameters, identify sources of fresh air, and detect regions that tend to accumulate pollution. These are integral in understanding the environment of a city and how air and pollution are transported within.

To complement identification services, a set of **Simulation Services** has been conceptualized, including the Heat Island Simulation and Mitigation Strategies Service, the City Air Flow Simulation and Mitigation Strategies Service, and the Pollution Simulation and Mitigation Strategies Service. These services grant users the ability to manipulate city models, create simulations to evaluate the impacts on various topics like Urban Heat Islands and city air flows, and receive suggestions for mitigation measures.

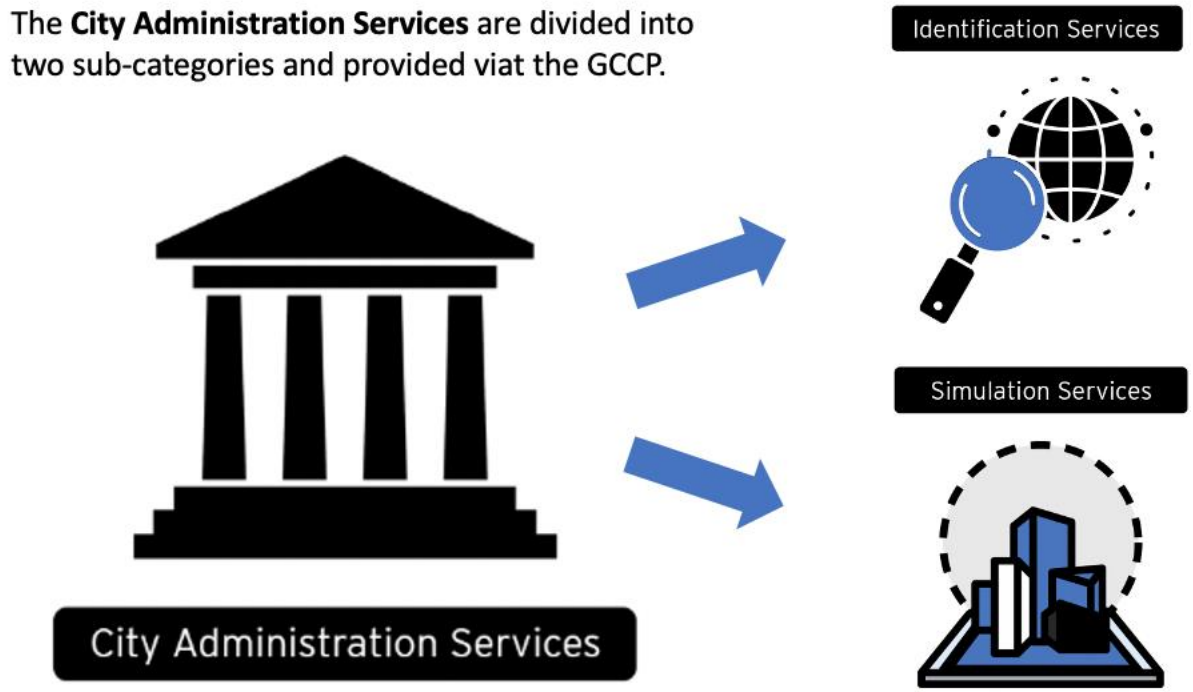

Figure 15: Schematic representation of the City Administration Services and its main features.

The Simulation Services have a user-friendly "Simulation Editor" where users can test out changes to city designs. After making these simulated changes, users need to pick specific days, called "days of interest," to carefully study the effects of their changes. There's also a "Model-Viewer" feature that lets users see all past climate-related data and simulations. This is a helpful tool when using other services because it gives a complete picture of past climate data and tests. These simulation services are crucial for making good plans to reduce the negative effects of climate change in cities and support understanding the possible outcomes of changing city designs.

The different services together create a system that helps make meaningful decisions about how to best respond to and reduce the effects of climate challenges in cities. They help pinpoint areas in the city with bad air flow, too much heat, or pollution risks, and offer solutions for these issues. These services are part of the GCCP and they work best when all their parts are used together. They can be very helpful for city leaders because they give detailed information and let users compare their tests with set standards about city climates.

2.5.1 Identification Services

The CityCLIM Identification Services stands as a groundbreaking tool for understanding the nuanced atmospheric interplays at play within the confines of urban microclimates. Urban planners, researchers, and city administrators often grapple with the intricate dance of various climatic factors that dictate the living conditions in cities. With increasing urbanization, the need to comprehend and manage these microclimates becomes paramount. CityCLIM's ability to tap into past UltraHD model runs (given an appropriate runtime) provides a rich data basis, enabling professionals to delve deep into historical local climatic patterns, understand temperature anomalies, and even compare specific areas within a city based on selected parameters.

These services allow to use the past UltraHD model runs (and their output data) that is automatically stored in the Climate Platform to aggregate them and gain further insights through aggregation. For example, with this service the user can mark certain areas of interest within the city and can compare them in regard to parameters like e.g., maximum temperature.

In the picture below, you see that the blue and green areas are compared with regard to the maximum temperature, depicting a heat island effect. The data is aggregated over more than one month and the green area (outer city area) clearly shows a significant difference to the blue area (inner city area).

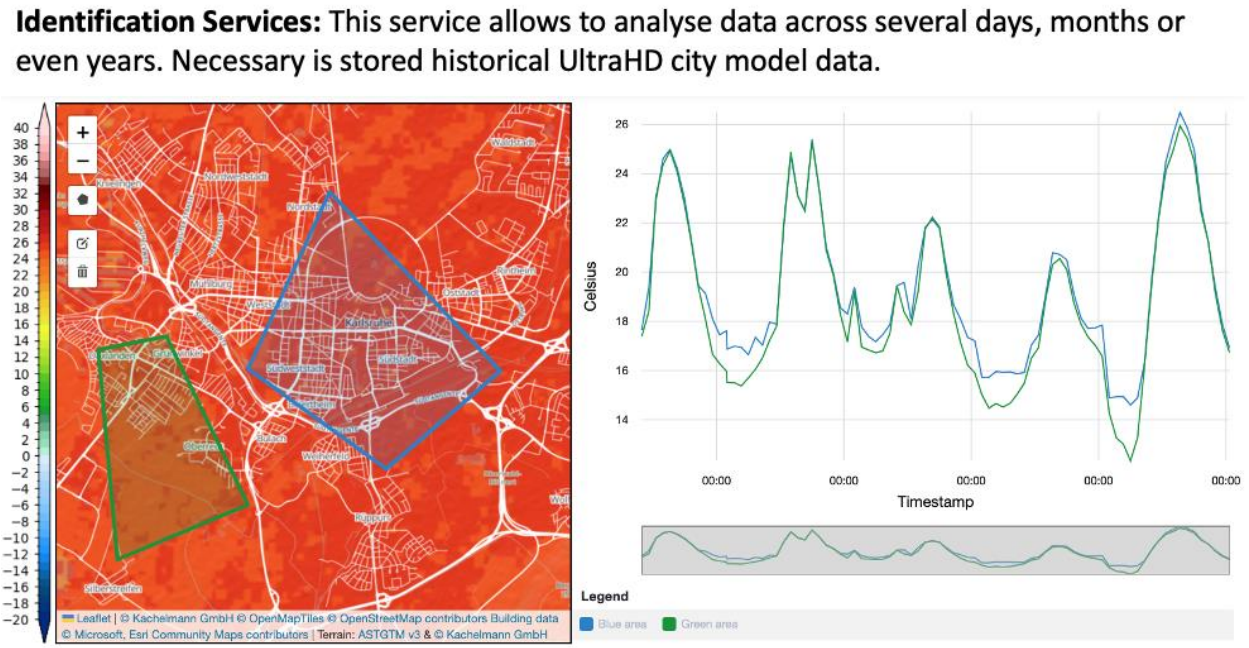

Figure 16: Screenshot of one CityCLIM Identification Service.

Decision-makers equipped with insights from CityCLIM's Identification Service can pinpoint areas that are particularly prone to UHI effects. By highlighting these hotspots, the service provides a roadmap for targeted interventions. For instance, understanding that an inner-city area consistently registers higher temperatures than its outer counterparts can lead to strategic planting of greenery, redesigning buildings to be more reflective, or introducing water elements to provide cooling. The graphical comparisons, like the differentiation between the green and blue areas based on maximum temperature, offer a visual cue that stresses the urgency and the areas of focus.

Beyond just temperature, the comprehensive understanding of a city's microclimate includes airflow patterns, which can significantly influence the city's ability to cool itself. The CityCLIM Identification Service provides crucial information on these gross airflow patterns. Such knowledge is invaluable for city planners and administrations. When contemplating significant urban developments or infrastructural changes, understanding how these alterations might disrupt or enhance the city's natural airflow becomes critical.

A city that can efficiently usher in fresh air and expel particulates ensures a healthier living environment for its inhabitants. This not only helps mitigate UHI effects but also paves the way for a more sustainable and livable urban landscape.

Fact Box 6: CityCLIM Identification Service

- ✓ The CityCLIM Identification Services are a pioneering solution that enables urban planners, researchers, and city administrators to comprehensively understand urban microclimates. By tapping into past UltraHD model runs, the services create a robust database that illuminates historical climatic patterns, temperature variations, and allows for comparisons between specific urban regions.
- ✓ This invaluable tool highlights areas particularly susceptible to Urban Heat Island (UHI) effects, providing a clear path for targeted interventions. Utilizing visual aids like temperature comparisons, CityCLIM assists decision-makers in understanding not only temperature anomalies but also crucial airflow patterns. These insights are essential for planning infrastructural changes, ensuring cities can maintain a healthier, more sustainable environment for their residents.
- ✓ Integrated and inclusive planning
- ✓ Testing of nature-based solutions
- ✓ Simulating of District-Cooling
- ✓ Simulation of effects of adding green-spaces or water bodies
- ✓ Simulation of changes to a city's geometry

2.5.2 Simulation Services

The CityCLIM solution includes a Simulation Editor that allows users to simulate local urban characteristics by adapting land cover types and elevation. The user can create a new set of simulated changes by drawing polygons of different colors representing different land cover types on a map. Clicking on the polygons allows the user to additionally enter elevation information. Every added information on the map is automatically saved, and already integrated changes can be reviewed and continued. Moreover, the user can request a simulated run by specifying a reference period, which then triggers the workflows of the simulation engine to produce manipulated EO data.

The user can request on-demand model runs. The service then calculats differences for certain parameters and model runs and produce maps using this data to study the influence of changes in land use or the digital elevation model.

2.5.2.1 Why is it important to be able to adjust land features?

The CityCLIM solution offers a way to tackle the Urban Heat Island (UHI) issue by supplying urban planners with a digital platform to test various strategies and solutions for intricate challenges. The Simulation Editor serves as a tool for planners to explore ways to alleviate UHI effects, as detailed in chapter 1. For example, it enables users to model the results of introducing vegetation, such as trees and other plants, in urban regions to lessen the heat intensity. This editor grants users the capability to generate new scenarios by sketching polygons, each color indicating a distinct land cover type, on a map. With this service the user can add trees and green spaces to the city map, observing in how much of an effect can be expected after implementing such changes. Trees and other plants can lower air temperatures by providing shade and cooling nearby air through "evaporative cooling," which is a natural process by which evaporating water absorbs heat. Vegetation also helps to reduce air pollution levels, which can worsen the effects

of UHI. In addition to vegetation, other strategies to reduce UHI include building cool roofs and pavements that feature bright coatings that reflect more sunlight and absorb less heat.

Beyond just vegetation, there are other approaches to diminish UHI, like constructing cool roofs and pathways that have reflective coatings, ensuring they deflect more sunlight and take in reduced heat. With the CityCLIM platform, urban planners can virtually test these methodologies prior to their actual application in the city.

Simulation Service: This service allows input data manipulation to simulate how a weather forecast would be if the local conditions in land use would change.

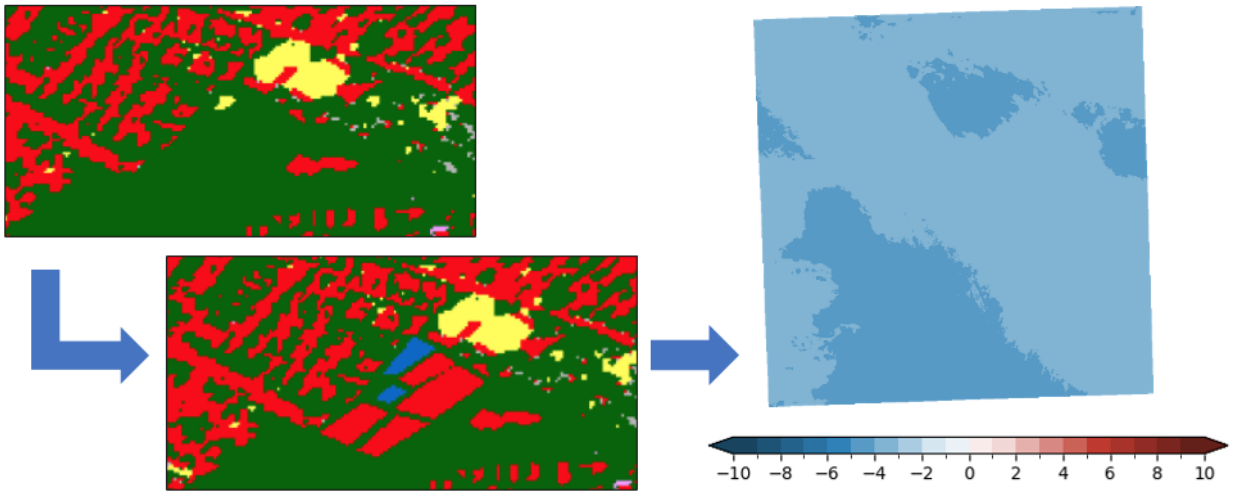

Figure 17: Schematic overview about the process of a Simulation service. The Simulation Service works by manipulating input data (usually land use and roughness by planting trees, manipulating sealed structures and so on). The manipulation of input data is not restricted to land use data, it is also possible to change elevation and for the future it is planned to add default scenarios (like greening of roofs, etc.). The changes through the user-defined modifications are depicted as a difference map (right).

Another special feature of these services is, that it enables users to actually observe long-term effects of existing mitigation strategies like mist showers that are used in Vienna and Paris to cool citizens down during extensive heat waves. It is possible that these strategies work well in the short term but could aggravate the situation in the long run as they add moisture to the air which worsens the heat stress especially during the night. These kinds of effects can be investigated with the CityCLIM simulation engine. The presented services cannot only deliver difference maps but also give percentages of change, indicating how certain actions affect the city's microclimate quantitively.

Fact Box 7: CityCLIM Simulation Services

- ✓ The CityCLIM Simulation Service offers urban planners a dynamic platform to virtually test various mitigation strategies against the Urban Heat Island (UHI) effects. This interactive tool enables users to experiment with introducing green spaces, trees, and other forms of vegetation, emphasizing the importance of green infrastructure in regulating temperature and improving air quality.
- ✓ Moreover, the service doesn't just focus on immediate changes; it also provides insights into the long-term implications of different strategies to ensure that decisions made today are sustainable and beneficial for the future urban environment.

2.6 Citizen Science Services

The CityCLIM consortium has created an extensive framework for the meaningful involvement of citizens in the participating Pilot cities that can be used as a template for interested cities.

Citizen scientists gather diverse types of data, ranging from environmental observations like plant sightings and water sample analysis to public health concerns and historical site documentation. Their involvement can be as simple as noting seasonal changes in plants or as intricate as participating in disease monitoring. The special role Citizen Science can play is that it directly involves citizens in the process of creating mitigation and climate adaption strategies while at the same time gathering data to support these strategies.

Becoming a citizen scientist typically starts with curiosity and a desire to contribute. Although the steps to participate can vary in dependence of the citizen science project, the general theme is a passion for discovery and a willingness to support the broader research community.

Becoming a Citizen Scientist in CityCLIM:

Data for CityCLIM is acquired, in part, from citizen scientists. Interested individuals can actively participate in various ways within the CityCLIM initiatives:

- ***Mobile Weather Sensor:*** Citizen are encouraged to use a portable weather sensor, MeteoTracker, to record data.
- ***Stationary Weather Station***: Data: Weather interested people can share data from their stationary weather stations, and sending their data to the CityCLIM's API.

  Historical Weather Data: Those with archived weather data, from personal records or old diaries, can share this to aid the understanding of historical climate patterns. There is an online upload tool available.

Additional Support for CityCLIM:

CityCLIM appreciates and encourages more than just data collection. Further contributions can include data analysis, data validation, storytelling to spread awareness, networking to expand the project's reach, training newcomers, refining collection methods, and sharing through various platforms like blogs and social media. Long-term commitments, like continuous monitoring, and efforts to find more historical data, are also important. These collective efforts help democratize science, promoting inclusivity and broader impact.

Acknowledging Contributions to CityCLIM:

Recognizing the dedication of citizen scientists is pivotal. CityCLIM is committed to rewarding and recognizing these efforts to ensure continued participation and convey gratitude for the invaluable support provided.

More information can be found in the Citizen Science Handbook available for free to the public and found on the CityCLIM.eu website within the library section: https://www.cityclim.eu/info-material

3 What is the process towards a functioning CityCLIM solution in your city?

The CityCLIM solution is open for anyone but generally aimed at city administrations and their partners as it is beneficial if the city itself is involved and interested in the exploitation and usage of the provided data. However, running a CityCLIM solution for universities or other research or even commercial institutions is also possible.

A detailed onboarding procedure, including a definite price structure can be provided on demand, however a general outline for the process that will be necessary to set up a CityCLIM solution in a given city is as follows:

3.1 General CityCLIM Onboarding Procedure

1. Initial Consultation:

- ✓ Introduction and overview: Understand the CityCLIM project, its benefits, and how it can help the city tackle urban heat island effects.
- ✓ Define city needs: Identify the city's unique requirements and challenges related to the urban microclimate.

2. Data Access & Integration

Station data:

- ✓ If the city has its own weather or climate stations, provide access to this data.
- ✓ If not, CityCLIM will initiate the setup of stations to collect necessary data.

Elevation City Model:

- ✓ Grant CityCLIM access to the city's 3D elevation model. (If unavailable, CityCLIM will utilize the Copernicus data as an alternative.)

3. Service Package Selection:

- ✓ Review Available Packages: Understand the various service packages offered by CityCLIM.
- ✓ Package Selection: The city should select the desired package(s) that cater to their specific needs and challenges.

4. Technical Set-Up and Integration:

- ✓ Server configuration: CityCLIM will ensure servers are set up and configured to handle the data and services for the city.
- ✓ Data processing: Start the periodic processing and provision of EO data based on the city's data and additional data from CityCLIM's stations (if set up).
- ✓ Coordinate system integration: If needed, the data will be mapped onto the WGS84 coordinate system for uniformity and easy integration into the CityCLIM GUIs.

5. Training & Support:

- ✓ CityCLIM platform training: Provide the city's relevant staff with training on how to use the CityCLIM platform effectively.
- ✓ Ongoing support: Offer continuous technical and user support for any challenges or queries.

6. Launch & Feedback:

- ✓ Soft launch: Test the CityCLIM services in the city to ensure everything runs smoothly.
- ✓ Feedback loop: Regularly gather feedback from the city to ensure the services are meeting their needs and make any necessary adjustments.

3.2 Requirements

There are no hard requirements besides the provision of the required funds. The funds are needed to cover the model computation server costs, the cloud and storage provision, the user and access management and first level support. The resulting output of the weather model data gets better the more “ground truth” is available, that means the more measurements are available in a sufficient timely resolution and the better the land use and elevation models are. However, there are open-data solutions available (Copernicus data) and other Earth observational data so that an initial launch should always be possible.

It is planned to offer hardware packages, that include the purchase and support in instalment of weather and air quality sensors within a participating city, which could enrich a measurement network if necessary.

4 Conclusion and Next Steps

4.1 Become a CityCLIM partner!

Improve your Urban Climate Strategy with CityCLIM's Advanced Solutions

Urban centers globally are facing intricate challenges related to Urban Heat Islands, distinct microclimatic variations, and the pressing imperative of sustainable urban development. CityCLIM offers a state-of-the-art, scientifically-advanced solution meticulously designed to cater to the unique climatic intricacies of contemporary urban landscapes. By integrating the CityCLIM system, municipalities not only underscore their commitment to understanding and addressing climatic challenges but also fortify their dedication to ensuring an optimal, healthful environment for their constituents.

We invite urban decision-makers and stakeholders to engage with us to explore the transformative potential of CityCLIM for your metropolis. Prioritize climatic resilience and sustainable urban planning—begin the dialogue with our team of experts today.

Empowering Smart Cities with Precision and Foresight through CityCLIM

Figure 18: SMART Cities and Digital Twins are perfectly suited for CityCLIM integrations.

In the era of smart cities and digital Ttwins, precision-driven data integration forms the crux of transformative urban solutions. CityCLIM's high-resolution weather model is tailor-made for such an advanced urban landscape, ensuring your city is not only smart but also climatically adept.

Integrating CityCLIM into your city's digital twin framework enriches the depth of real-time insights available, elevating your smart city to be both reactive and proactive to weather and climatic challenges. With our holistic suite comprising vital information, timely warnings, and detailed climatic data, ensure that your smart city is truly responsive, adaptive, and future-ready. This is more than just data; it's a strategic toolset that augments every facet of your urban planning and management endeavors.

4.2 Contact & Updates

To get updates on CityCLIM, you can visit the CityCLIM website at cityclim.eu and subscribe to the newsletter. You can also follow us on social media platforms such as Twitter (X) and LinkedIn, and ResearchGate. If you have any questions about the project or are interested in collaboration, you can contact them by filling out the form available on our website.

Find us on:

- LinkedIn
- Twitter (X)

4.3 Outlook

The CityCLIM project remains in active development, reflecting our dedication to continuous improvement and refinement of our framework and the solutions derived from it. Our team is committed to ensuring the quality and relevance of the tools and services we provide.

We keep working on and improving our framework and the resulting solutions. We are also still improving our comprehensive business concept, so we can provide our potential customers an elaborate but easy and transparent solution that is **a) easy to budget and features b) seamless integration** so that we can quickly start seeing results from our integrations and running solutions.

The next handbook will provide you with our subscription matrix, a first detailed pricing concept and the updates on our services that the CityCLIM framework can offer you.

Fact Box 8: CityCLIM Key Take Aways!

- ✓ **CityCLIM aims to equip cities with tools and insights to understand and mitigate urban climate challenges, such as the Urban Heat Island effect, through specialized services and data-driven solutions.**
- ✓ **CityCLIM provides specialized services in two core areas:** Citizen Climate Knowledge and City Administration Services. The first educates and engages citizens about urban climate dynamics and potential hazards, especially in pilot cities. The second offers decision-makers tools to comprehend and simulate urban climate patterns, like heat islands and pollution, via user-friendly web interfaces.
- ✓ **CityCLIM is your gateway to advanced climate intelligence.** Ideal for City Administrations and institutions alike, CityCLIM offers tailored solutions to urban climate concerns. From personalized consultations to top-notch technical infrastructure like 3D modelling, we ensure a smooth experience. Our diverse service packages cater to your city's specific needs, backed by comprehensive training and support. Additionally, our upcoming hardware packages, featuring premium sensors, will further enhance your city's data treasure.
- ✓ **With CityCLIM, transform your city into a climate-responsive urban masterpiece!**

5 References

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About CityCLIM

The strategic objective of CityCLIM is to significantly contribute to delivering the next-generation of City Climate Services based on advanced weather forecast models enhanced with data both from existing, but insufficiently used, sources and emerging data sources, such as satellite data (e.g., Copernicus data) or data generated by Citizens Science approaches for Urban Climate Monitoring etc. For City Climate Services, data products of interest related to land surface properties, atmospheric properties (e.g., aerosol optical thickness), geometry etc. For all of those, information of interest concerns e.g., Copernicus data products and services that are already existing (e.g., based on Sentinel-3/OLCI, PROBA-V, SPOT, Sentinel-1, MetopASCAT data), will exist in the near future (based on already flying satellites such as Sentinel-2), or will exist in the mid-term (based on satellites currently under development) and long-term (based on satellites soon starting concept phase) future. The project will establish; (i) an open platform allowing for efficient building of services based on access to diverse data; (ii) enhanced weather models based on data from diverse existing and emerging sources; (iii) a set of City Climate Services customizable to specific needs of users in cities; and (iv) a generic Framework for building next generation of Urban Climate Services. CityCLIM will be driven by 4 Pilots addressing diverse climate regions in Europe (Luxembourg, Thessaloniki, Valencia, Karlsruhe) which will define requirements upon the tools to be developed, support specification and testing of the services and serve as demonstrators of the selected approaches and the developed technologies. The consortium will elaborate business plan to assure sustainability of the platform and services.

Every effort has been made to ensure that all statements and information contained herein are accurate, however the CityCLIM Project Partners accept no liability for any error or omission in the same.

Funded by the Horizon 2020 Framework Programme of the European Union