Ref. Ares(2022)4800925 - 30/06/2022

HORIZON 2020

The EU Framework Programme for Research and Innovation

Benchmarking, Scenarios & Economic Feasibility Report

Deliverable D6.2

DATE

30 June 2022

ISSUE

1.0

GRANT AGREEMENT

no 870337

DISSEMINATION LEVEL

PU

PROJECT WEB-SITE

http://cure-copernicus.eu/

LEAD AUTHOR

Birgitte Holt Andersen (CWare),

Amaia Sopelana (TECNALIA)

CO-AUTHORS

Dirk Lauwaet (VITO), Filip Lefebre (VITO), Louise Kjær-Hansen (CWare), David Ludlow (UWE)

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1 INTRODUCTION

1.1 Introduction to the CURE project

Cities are exceptionally vulnerable to climate change and their vulnerability is increasing over time. Climate change has several direct and indirect impacts on cities and citizens. Risks related to urban heat island phenomenon, floods and air pollution are critical for the security and resilience of the cities and are further amplified by climate change. These direct and indirect impacts of climate change challenge the economy and quality of life in cities and in Europe as a whole. Resilience has become an important necessity for cities, particularly in the face of climate change. Mitigation and adaptation actions that enhance the resilience of cities need to be based on a sound understanding and quantification of the drivers of urban transformation and settlement structures, human and urban vulnerability, and of local and global climate change.

To consider these effects, information on urban form and function at different spatial and temporal scales is needed and the potential of Earth Observation (EO) to provide this information is high. Though there is a wealth of EO-derived information – even available in global coverage, this information is not necessarily translated into the required knowledge. Tailored, scalable, and context relevant information for effective and timely climate action at the local level is missing.

The use of EO and its integration with other community-driven information sources could step up to the challenge. Copernicus, as the means for the establishment of a European capacity for EO, is based on continuously evolving Core Services. A major challenge for the EO community is the innovative exploitation of the Copernicus products in dealing with the multidimensional problem of urban sustainability towards increasing urban resilience.

The urban planning community needs spatially disaggregated environmental information at local (neighbourhood) and city scales. Such information, for all parameters needed, is not yet directly available from the Copernicus Core Services mentioned above, while several elements - data and products - from contemporary satellite missions consist valuable tools for retrieving urban environmental parameters at local scale.

Therefore, to address urban resilience, cross-cutting applications among the Copernicus Core Services are needed, which should also be capable of coping with the required scale and granularity by integrating or exploiting third-party data, in-situ observations and modelling.

Urban environment was not specifically taken into account during the design of the current Copernicus Core Services. Therefore, the H2020 project CURE (Copernicus for Urban Resilience in Europe) explores to what extend CURE can provide the means to cope with the EO data under-exploitation in the domain of sustainable and resilient urbanization thus the potential of Copernicus to support sustainable and resilient urbanization still remains underexploited.

CURE synergistically exploits Copernicus Core Services to develop cross-cutting applications for urban resilience. CURE therefore enables Copernicus to better serve applications at European scale by introducing novel ideas on how applications for climate change adaptation and mitigation, healthy cities, and social environments, as well as energy and economy can be developed across Copernicus Core Services.

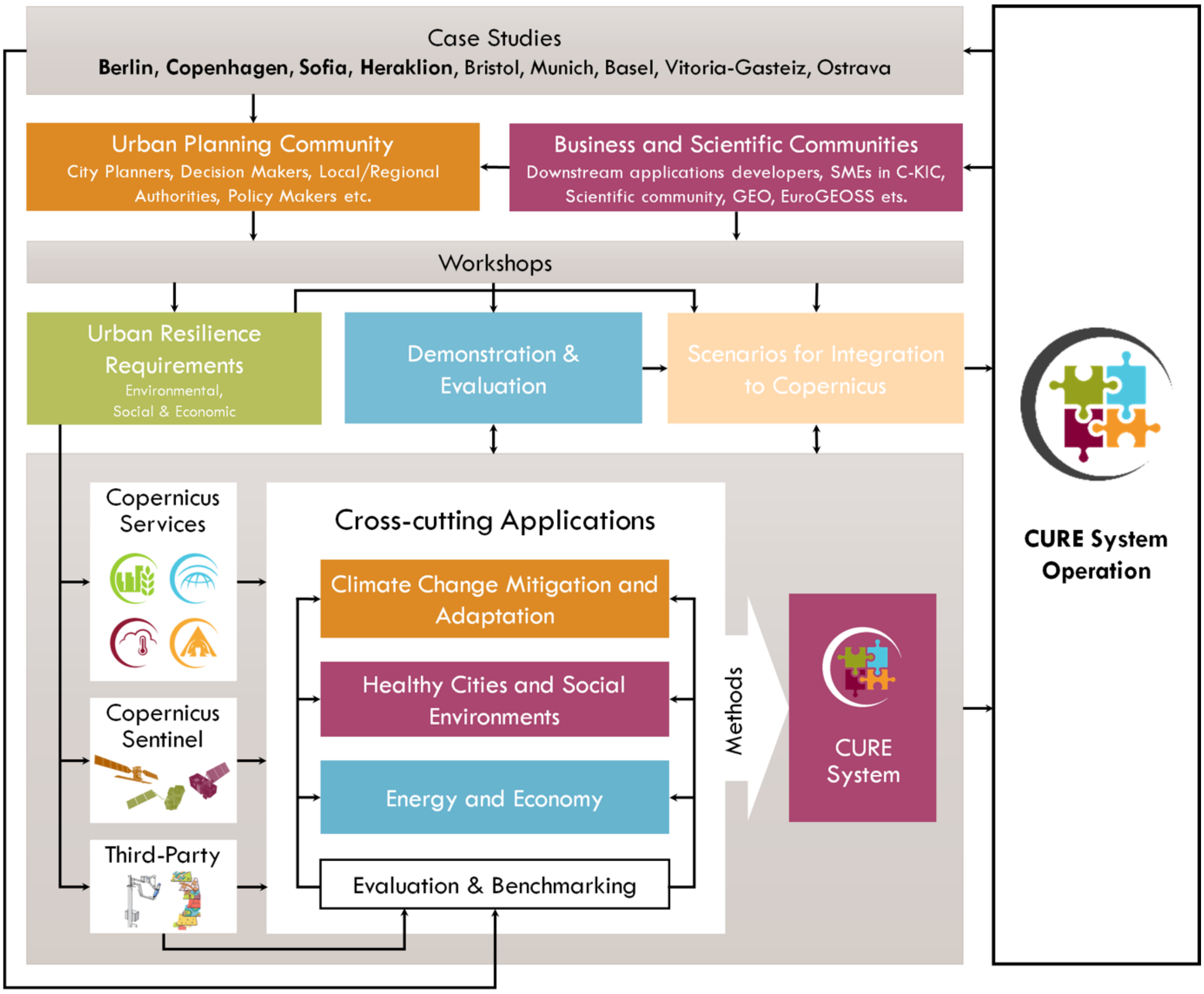

Figure 1-1 Overview of CURE concept

1.2 Purpose of this deliverable

The aim of this deliverable is to access the CURE services against its real impact for the stakeholders considered. The work builds upon the data collection and results of Task 6.1 the Scenario Development (D6.1) complemented by further data collection and literature research.

A benchmarking analysis will identify the advantages and the qualitative and quantitative benefits of CURE with respect to actual alternatives, in terms of costs, time, data availability, maintainability of the system and data update frequency. This competitive analysis will be enriched by the end users' perspective gathered in the demonstration workshop of WP5.

A classical economic feasibility approach will be applied. The economic feasibility task will consolidate and use the results from across the other WPs, but in particular from Task 6.1, Task 6.2 and WP5 demonstrations. The economic feasibility will assess the cost-of-service delivery at local, regional and EU level given the different scenarios outlined in WP6.1. It will assess the benefits to be delivered, likewise at local, regional and EU level compared to baseline. It will assess the different type of risks towards implementation. Finally, we will look at exploitation and funding issues, including how the CURE service could be a candidate for Copernicus operational funding.

1.3 Outline of document

Chapter 2 reports on the results of the Benchmarking assessment

Chapter 3 reports on the results of the Economic feasibility assessment.

Chapter 4 conclude the combined assessment and summarise the main strategic considerations and challenges for the further exploitation of the CURE project.

Acronyms

CURE	Copernicus for Urban Resilience in Europe
DIAS	Data and Information Access Services
DMP	Data Management Plan
EAP	Environmental Action Plan
EC	European Commission
EEA	European Environment Agency
EO	Earth Observation
EU	European Union
FORTH	Foundation for Research and Technology Hellas
H2020	European Union’s Horizon 2020 research and innovation programme
ICT	Information and Communication Technologies
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
KIC	Knowledge and Innovation Community
NBS	Nature-Based Solutions
SDG	Sustainable Development Goal
UHI	Urban Heat Island
WP	Work Package

2 BENCHMARKING

2.1 Objectives and Benchmarking approach

The main objective of this benchmarking analysis is **to measure the performance of CURE applications' functionalities against solutions already existing on the market that provide similar services to the user**. Its results will provide internal opportunities for improvement in terms of a range of criteria, technical and non-technical.

When talking about benchmarking, external benchmarking is suitable for the objective of evaluating how the CURE applications model or monitor different aspects related to urban resilience regarding energy and economy, climate change adaptation and, healthy and social environments.

In the CURE project, benchmarking as a procedure is used to evaluate the performance of solutions currently used by urban planners or regional/national/urban authorities, or institutes providing pan-European data against a set of defined standards which will represent a tangible impact on the stakeholders considered.

The benchmarking methodology, based on (Henderson-Smart et al., 2006) was adapted to the CURE context and the main steps are as follows:

1. **Planning**: determine **what to benchmark**, identify **criteria**, determine **data collection method**, and **collect data**; (from Step 0 to Step 3)
2. **Analysis**: **understand performance gaps**, and **predict future performance levels** (Step 4 and Step 5)

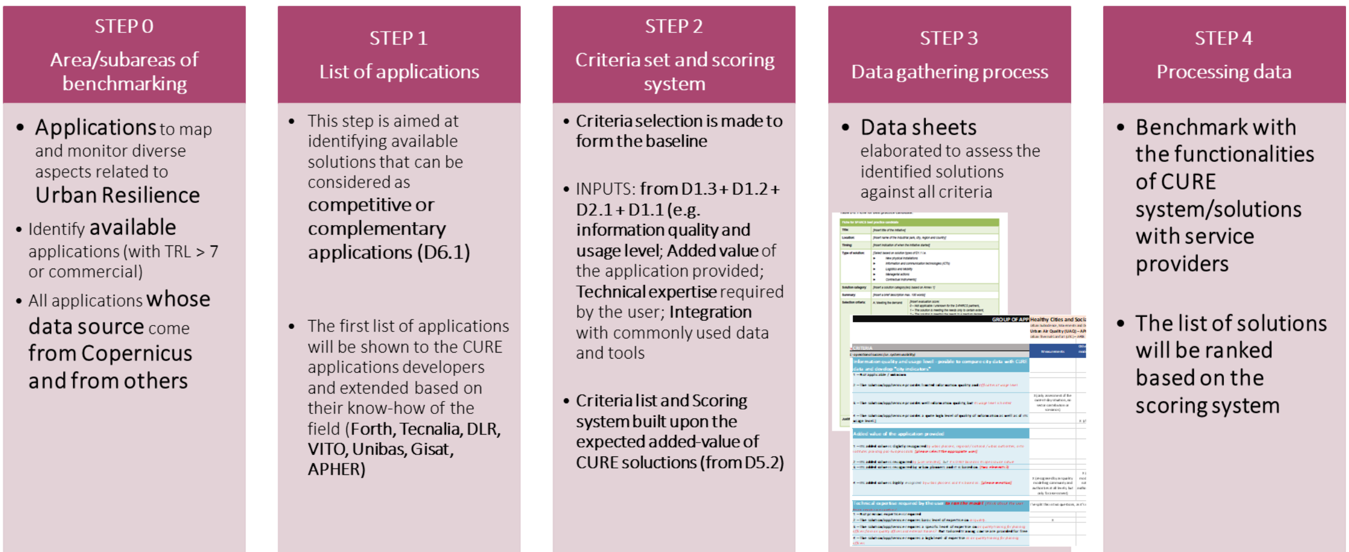

Figure 2: Benchmarking steps propose for CURE context

Having established the boundaries of the analysis, the first step focused on exploring current **services and practices** used by the end-users which provide similar functionalities to CURE apps. They were selected by evaluating the user requirements as well as the potential functionalities that CURE apps are providing. For this aim, a systematic review of the outcomes stemming from D1.2, D1.3, D2.1 help identify all existing models or applications that form the **competitive landscape**.

As a second step, a sound selection of the "defined standards", hereinafter "criteria", to form the baseline against those applications will be evaluated. They represent the **added value of CURE applications or targeted aspects** of the models/monitoring performance to be evaluated. Results from the previous stage were enriched with the feedback received from service providers in D6.1 and stakeholders taking part in the demonstration workshop of WP5. In this sense, the WP5 was focused on assessing the usefulness of CURE applications in decision-making processes within the frame of open, integrated and interoperable governance. Specifically to assess the outcomes of the CURE applications from the perspective of benefits to potential users and the relevance to the stated or implied objectives of the project.

Additionally, to the criteria, a **scoring system** is needed to make easier the benchmark exercise, that is, how the apps, models, or monitoring results achieve the relative performance. Then, the analysis can provide expected **improvement areas** where the model/app, hereinafter data products, are sufficiently robust. Expert knowledge of the service providers also complemented relevant insights to establishing the scoring system.

It is worthy to note that the focus of this benchmarking analysis is only on non-technical aspects of the CURE applications. One of the main aims of this task is to show **the data products' strengths and deficiencies for future improvement**. It is challenging to identify model deficiencies in structure based upon diagnosis of poor performance from various users' perspectives.

The four steps of the benchmarking scheme adapted to CURE solutions are described in detail in the following sections.

2.2 Steps 1, 2 and 3 (Data gathering process)

2.2.1 Inputs from previous analyses

In D6.1, the socio-economic perspective of the CURE APPs was evaluated concerning primarily three factors, namely:

(1) the scalability of the individual services, meaning how easy can the methodology and delivery be replicated for another city, this also includes the readiness of the service

(2) the added value of the services for the user compared to other services

(3) the economic feasibility of the service, meaning the cost-effectiveness compared to other solutions and the potential business model for service delivery

These criteria could be used to define requirements for the services to be included in the future CURE service portfolio. As a result, in that report, a first assessment of the 11 applications currently being tested in the CURE project according to these 3 dimensions was deployed. The following table shows only the added-value aspect which covers the questions concerning non-technical assessment considering the users' expectations of the CURE apps when compared to alternative solutions:

	ADDED VALUE
APP01 Local scale surface temp dynamics	Use case unclear
APP02 Surface UHI assessment	Use case unclear
APP03 Urban heat emissions	Use case unclear
APP04 CO2 emissions	Use case unclear
APP05 Flooding	Similar to other services available
APP06 Urban Subsidence	Risks of subsidence
APP07 Urban AQ	Many similar services
APP08 Urban Thermal Comfort/UrbClim	Use case clear
APP09 Urban Heat Storage	Use case unclear
APP10 Nature based solution	Use case broad. For the potential for green roofs the use case is clear
APP11 Health costs of AQ	Use case clear, health cost of AQ

The questions included to explore the added value for scientists/urban stakeholders over existing services were:

Question 4: What is the added value for scientists/urban stakeholders over existing services?

- Is there any commercial service available in the market that provides a similar solution? (i.e. which are the main "competitor services" offering alternative solutions to yours)? (Note: please list the "applications")
- What are their strengths and weaknesses compared to your service?
- Do you know of any new service in the progress of development (with TRL 7 or 8) that could compete in the future with your service?

All these questions helped us to identify the strengths of CURE APPs as well as available solutions or services in the market.

2.2.2 Literature review on benchmarking analyses on the CURE subject areas

There exist some comparative assessments of different models discovered on the first stage that can be found in scientific literature. Nevertheless, these types of analyses are commonly made considering specific aspects of urban resilience which can be related to some of the CURE applications.

Aydin et al. (2019) compare the use of 4 prediction tools for urban microclimate assessment from a user perspective, with particular focus on the helpfulness of results for the decision-making process, concerning capabilities, limitations, ease of use and accuracy (Aydin et al., 2019). The tools analysed are SOLENE (Miguet et al., 1996), ENVI-met (Bruse and Fleer, 1998), RayMan (Matzarakis et al., 2007), SOLWEIG (Lindberg et al., 2008), STEVE (Jusuf and Hien, 2009) and aims to assess their usability on thermal comfort and Urban Heat Island through the application in a case study in Singapore.

The ease of use was focused on the data entry specification needed to represent the urban context as well as on the comparison of interfaces, inputs and output generated. Each tool requires a different model, specifically grid-based, pixel-based points or Digital Surface Model (DSM), thus requiring specific knowledge to generate it and which is not usually common to urban planners. Data entry efforts and speed criteria, which vary across the tools used, were also assessed as crucial parameters. Two of the tools (RayMan and SOLWEIG) generate results for a single point of interest, while the others allow obtaining results across a grid of points of the urban model. In terms of accuracy, the results demonstrated that there is an acceptable range of error. Nevertheless, it was demonstrated that the most comprehensive tool (ENVI-met) in terms of capabilities is the slowest one, while the narrow scoped (STEVE) has the most accurate results. Still, the level of knowledge necessary to use the tools is high and improvements oriented to final users are still needed.

The review proposed by (Nkwunonwo et al., 2020) addresses several flood models developed forward from 19990, considering as main criteria spatial extent, dimensionality and mathematical complexity. Even if the paper addresses the specific problem of urban flood risks and developing countries and data-poor areas, it makes a valuable contribution to assessing different models in the field. The analysis considers the different types of modelling, specifically: i) one-dimensional flood models such as ISIS, MIKE11 and HECRAS; ii) two-dimensional flood models such as TUTFLOW, SOBEK and MIKE 21; iii) three-dimensional models and iv) models based on simple mathematical complexity. As a result of the research, most of the models cannot be conveniently applied in developing countries, due to the lack of high-resolution topographic data and end computing facilities, which represents a major barrier. Furthermore, the lack of a reliable intensity-duration-frequency (IDF) model is also a limitation. It is recognized that remote sensing technologies offer new possibilities to overcome data limitations, as long as costs are reduced and kept low and data processing or software requirements are feasible.

Urban surface floods models and approaches have also been reviewed by (Guo et al., 2021). The research undertaken explores the advantages and limitations of existing models, considering their complexity, the scale effects and the computational efficiency. Besides the data commonly used for river floods, the study analyses the dynamics in complex urban systems, which present substantial modelling challenges associated with the irregular topography with buildings, drainage networks, critical infrastructure and surface heterogeneity. Four groups of models are analysed: i) drainage network models; ii) shallow-water based models; iii) hydrogeomorphic approaches and iv) cellular automata and artificial neural networks. For this purpose, a literature review was performed to determine how surface flood models have been developed and applied. The study highlights the improvements in remote sensing technologies to provide data more readily available. Nevertheless, it also stresses the importance of calibration and validation as well as the need to combine terrain data with buildings maps and land use and ensure sufficient grid-scale to meet accuracy requirements. Models supported by satellite-based data are mostly applied to fluvial floods but are rarely applied to urban pluvial floods. The paper provides insights into urban flood models and highlights the need for advancing developments to raise real-time applications with better resolutions in the future.

A more holistic approach is considered in the comparative assessment of (Keibach and Shayesteh, 2022), which evaluates different software tools for climate adaptation of landscape design. Five tools (ENVI-met, Lady-bug, GreenScenario, CitySim and AST) were selected and compared using the ISO 25010, evaluating their functionality, reliability, performance, usability and compatibility, together with information quality which is not covered by the ISO framework. This aspect is therefore assessed by comparing the final output produced by each software in the same case study. The paper presents an overview of the limitations of the tools as well as the main differences among them. The main results are related to the common problem of software interoperability, data loss and functionality, stressing the low compatibility with common planning tools, which required adjustment or remodelling. Furthermore, each tool presents different functionalities of climate adaptation, but a complete model for the complex calculation of the impacts of adaptation measures in landscape design is missing, a barrier which may be overcome by the combination of the tools if interoperability is achieved.

2.2.3 Evaluation criteria and scoring system

It is worthy to note that this chapter does not aim to evaluate the users' requirements from a strictly technical perspective since most of them have been covered in WP1, WP2 and WP5. The focus of this selection of criteria is to provide an assessment of those key relevant criteria from a more non-technical assessment considering the users' expectations of the CURE apps when compared to alternative solutions.

Functionality

These criteria are built upon three main aspects: Information quality & Usage level, Added value provided by the application and Maintainability of the system.

When talking about the *Information Quality*, it refers to evaluating not only the *accuracy* of information the user is expecting (how accurate the simulations or calculations are in terms of quality (e.g. resolution scale, level of detail, etc.) but also the *suitability* for informing on the thematic areas of urban resilience (e.g. only assessment of the current-day situation, no sector contribution or scenarios, the maps are used as input for climate assessment and adaptions plans in several cities throughout Europe, etc).

In this regard, from the user requirement perspective, there is quite a significant demand for high-resolution data output from the CURE data products (from a few meters to 100 meters) data and high-frequency data e.g., hourly dynamics of heat emission (source: D1.1). Moreover, as mentioned by stakeholders "[…] CURE apps should be user friendly for all and that day-to-day usability of the CURE apps within municipalities should be one of the most important outcomes of the CURE project. […] *one of my ideas is that what will be developed must be of great usability for all. (...) the usability, I think, is one of the most important things"*.

Functionality also covers the *Added Value* provided by the APP when referring to providing effective urban resilience decision-making support. Hence, the added value will be higher as long as the level of recognition achieves international levels or, in other cases, because the number of potential users is higher (not only urban planners, but also regional/national/urban authorities, or institutes providing pan-European data).

User Skill Level

The technical expertise of the user has been mentioned in several feedbacks coming from both stakeholders and users. This group of criteria ponders user engagement. On the one hand, the required knowledge and expertise of the user when running the model is evaluated, that is if the dependency on the service provider is high. The expert knowledge to interpret the results provided by the APPs, on the other hand, is also evaluated from the perspective of urban planners. Some CURE APPs do not have enough maturity to provide understandable results or models further than the scientific community.

Compatibility

Compatibility evaluates co-existence with other software tools and/or the possibility of importing city data. This group of criteria was formed by three key characteristics that have been very valued according to the feedback received from users' requirements (WP1) and stakeholders (WP5):

- Integration with commonly used data and tools,
- Benefits of combining existing city data and CURE data
- Linking city data with the APP to develop indicators monitoring targets

Having captured from the experts' feedback (D1.1) that it would be interesting to have *integration of the CURE applications with other databases* (e.g. the EU collecting data about risks behind natural events such as earthquakes or climate adverse events). Stakeholders in the WP5 workshop stated that there is interest from their city to understand how they can be integrated into their existing systems and "… *not just see them on a slide"* (Stakeholder in D5.2). In this regard, although it has been highly rated by the respondents, the service providers mentioned that there is not a lot of commonly used data for instance, for urban air quality or thermal comfort, and this is probably true for most CURE applications. All service providers ranked this criterion with low levels of achievement mentioning that if it is possible, it depends on the technology provider in most of the cases and two APPs enable the integration with GIS.

The *benefits of combining existing city data and CURE data* appeared relevant from the requirements as well as stakeholders' perspectives. From the evaluation of users' requirements, an open-ended question was presented to ask respondents to specify any additional data/information that they would like to receive from the CURE applications. They grouped responses into a word cloud that indicates the frequency of various keywords such as information, building, climate, energy, planning, heat, green, emissions, transport, area, risk, air, quality etc. derived from examples such as *"CURE should provide a single point of access for various datasets of different applications through one map" or "CURE should be able to use and provide data combination of satellite-based, EU databases (e.g., risk behind natural events – earthquakes or other adverse events caused by climate change) and local data (i.e., sensors data, transport data including transport conditions, social activity data such as walkability, etc), smart city"*. Moreover, participants in the demonstration workshops also reinforced these arguments when some of them mentioned how *their city's official modelling data is incorrect, meaning that the incorrect data is being used to provide evidence, resulting in unrealistic and untargeted measures. They gave specific city examples of data discrepancies whereby official modelling showed low emissions, and modelling provided by an NGO showed higher emissions. The stakeholder expanded on the effects of the city's incorrect modelling, which resulted in unrealistic measures that cannot be targeted, and thought that the official modelling was unsuitable for urban planning*. Other stakeholders explained *how their city has very detailed data, to the extent that colleagues within the local authority cannot see the benefits of CURE data. However, the stakeholder's view was that combining existing city data and CURE modelling data would offer good city estimations*. In this case, the higher level of benefits coming from combining existing city data with CURE data represents that CURE APPs can connect with the vast majority of city data related to the urban planning field.

Finally, the possibility of *linking city data with the APP to develop indicators monitoring targets* such as information on local emissions, traffic data, industrial sources, and heating devices. During the stakeholders' workshop, an overall consensus was accomplished about the value of the CURE process of ongoing stakeholder engagement in CURE application development as "urban planners and downstream services developers are fully aware of what data is needed". They highlighted the benefits of providing cities with the opportunity to work with the CURE apps and understand how they can best be integrated into the existing cities' systems.

Decision-Making Process

This group of criteria implies generic aspects related to the implementation phase of urban planning and how the CURE APPs can assist managers in defining an appropriate action plan. It covers:

- Meeting demand: a local authority that wants to know the current situation and make action plans
- Translating evidence from data into action
- Price value of the solution

As stated in D5.1, positive affirmation of the user need for the full range of CURE apps was generated across all 3 themes of engagement. For climate change, mitigation and adaptation efforts to develop and deliver mitigation and adaptation plans were identified as "greatly undermined" by gaps in the available data including transport and traffic flows inhibiting calculations of CO_2 emissions. Similarly, for flood risk, flood risk analysis was viewed as challenging as "more detailed analysis of flood risk and preventative measures effectiveness are required". And finally, the relevance of the CURE air quality map was emphasised which in combination with the specific cross-cutting health impacts and thermal comfort apps supports the creation of healthy cities. Overall the CURE should aspire to *meet all users' demands* handling relevant competitive advantages in comparison with the competitors.

The dialogue among stakeholders also provides relevant insights into the current roadblocks that urban planners have to overcome when they have to develop, for instance, the climate change mitigation and adaptation plan, together with the sustainable energy development plan, but, that there were "gaps" in the plans due to lack of available data (e.g. calculation of CO_2 emissions; as there is no reliable data on transport, traffic volumes, or waste emissions, and lack of detailed data on flooding, intensive rainfall and resulting flood water distribution, etc.). This is the reason for integrating the criteria of *translating evidence from data into action* in order to measure to which extent the APPs will provide robust information to build consistent action plans for climate change mitigation and adaptation and healthy cities. Additionally, they also highlighted that there is a disconnect between the urban planning department and other departments, for example, air quality and energy, and an absence of data gathering resulted in poor intelligence provided to the urban planning department. The expected accomplishments (maximum score) show how the urban planners can go beyond being able to use CURE app data to adapt Action Plans through implementing citizen science campaigns that foster behavioural changes.

Last but not least, the *price value* is usually the most relevant aspect when urban planners (public authorities) are evaluating implementing new procedures or new digital tools to support their decision-making processes. Although cost structure is evaluated as part of the feasibility analysis (Section 3.5), this criterion considers the generic perception of the users concerning the accessibility of urban planners to such SW tools. In this sense, the highest score resembles that the final price of the APPs is reasonably low and competitive (for users).

The scoring system used, as mentioned before, has been established with the scores from 1 (low performance) to 4 (highest performance) representing how the APPs are providing performance concerning the criteria evaluated.

2.3 Step 4 - Benchmarking results

The 11 APPs have been grouped according to previous practice in the WP5 demonstration workshop as Figure 3 shows:

Climate Change Adaptation		Climate Change Mitigation		Health, Air quality and thermal comfort	
APP	SERVICE PROVIDER	APP	SERVICE PROVIDER	APP	SERVICE PROVIDER
AP10	TECNALIA	AP01	FORTH	AP07	VITO
AP05	GISAT	AP02	DRL	AP08	VITO
AP06	GISAT	AP03	UNIBAS	AP11	CWARE
		AP04	UNIBAS		
		AP09	FORTH		

Figure 3: Three groups of CURE applications

This chapter further investigates the information gathered from different service providers of the software tools, which can be divided into the main groups mentioned in the previous section.

2.3.1 Climate change mitigation

Within this group, a summary of the results concerning the following three APPs is provided. The results of the benchmarking are very dependent on the low level of technological maturity of some applications such as the cases of AP03, AP04 or AP09. The general overview of the assessment is shown in Table 1:

Climate Change Mitigation – Heat and CO2 Emissions														
CRITERIA	AP01	Alternative solutions					AP02		AP03	Alternative solutions		AP04	Alternative solutions	AP09
	LSSTD	in-situ measurements of LST	Thermal Camera	Thermal Camera Drone/Airborne	Copernicus LST	High-resolution Satellite LST	SUHIA	Schwarz et al. (2011)	UHEM	ENVI-met	in situ measurements flux towers	UCO2EM	in situ measurements flux towers	UHSM
FUNCTIONALITY														
Information quality & Usage level	4	3	3	3	3	4	3	1	3	3	2	4	2	2
Added value provided by the application			1	3			3	2	3	3	4	3	4	2
USER SKILL LEVEL: Technical expertise required by the user														
TO RUN THE MODELS, SIMULATIONS	3	1	1	1	3	3	2	3	1	4	1	1	4	1
TO INTERPRET THE RESULTS							3	3	1	1	1	3	1	2
COMPATIBILITY														

Climate Change Mitigation – Heat and CO2 Emissions

CRITERIA	AP01	Alternative solutions					AP02		AP03	Alternative solutions		AP04	Alternative solutions	AP09
	LSSTD	in-situ measurements of LST	Thermal Camera	Thermal Camera Drone/Airborne	Copernicus LST	High-resolution Satellite LST	SUHIA	Schwarz et al. (2011)	UHEM	ENVI-met	in situ measurements flux towers	UCO2EM	in situ measurements flux towers	UHSM
Integration with commonly used data and tools	1	1	1	1	1	1	1	1	3	2	1	3	1	3
Linking city data	1	1	1	1	1	1	1	1	3	3	1	3	1	1
Benefits of combining existing city data and CURE data	1	1	1	1	1	1	1	1	1	1	1	2	1	1
DECISION-MAKING PROCESS														
Meeting demand (action plans)	4		2	2		3	3	2	2	2	1	1	1	1

Climate Change Mitigation – Heat and CO2 Emissions														
CRITERIA	AP01	Alternative solutions					AP02		AP03	Alternative solutions		AP04	Alternative solutions	AP09
	LSSTD	in-situ measurements of LST	Thermal Camera	Thermal Camera Drone/Airborne	Copernicus LST	High-resolution Satellite LST	SUHIA	Schwarz et al. (2011)	UHEM	ENVI-met	in situ measurements flux towers	UCO2EM	in situ measurements flux towers	UHSM
Translating evidence from data into action	3	2	2	2		2	1	1	1	1	1	1	1	1
Price Value	3	2	2	2	3	3	4	2	4	2	1	2	2	1
TOTAL SCORE	**20,0**	**12,0**	**14,0**	**16,0**	**14,0**	**18,0**	**22,0**	**17,0**	**22,0**	**22,0**	**14,0**	**23,0**	**18,0**	**15,0**

Table 1: Models/apps assessment of Climate Change Mitigation group

Overall, the results revealed that CURE APPs are positioned at a slightly superior level in comparison to other alternative solutions except for the urban heat-emissions service in which, ENVI-met is providing similar performance that CURE AP03.

Firstly, the results about **functionality** aspects show that the most efficient applications are AP01 – which offers sufficient temporal coverage (up to 6 times per day) with a spatial resolution (100 m) suitable for accessing the intra-city heat load, similar to High-resolution Satellite LST while other measurements provided by conventional tools (such as in-situ measurements of LST, Thermal Camera, Thermal Camera Drone/Airborne, Copernicus LST) – and, AP04 that gives an overview of total CO_2 emissions, as well as the individual contributions of CO_2 sources/sinks from traffic, buildings, population and vegetation. However, it should be noted that AP04 is a prototype application, it provides qualitative high-level information, but the quantitative evaluation is only possible in the source area of the flux tower. While looking at the *added value*, it is remarkable that CURE AP01 will provide dynamic (high temporal resolution) local scale surface temperature (of high spatial resolution, 100 m) maps, with algorithms designed for the retrieval of urban temperature (accounting for the variability of urban materials) outperforming available solutions such as Landsat and ASTER, but these provide low temporal resolution. Considering that AP03 and AP04 are more valuable for the scientific community among which it is highly recognized but less useful for urban planners, the AP03 *added value* relies on the localization of hot spots of high heat emissions which will help urban planners to optimize their adaption strategies also with regard to heat stress, urban green space and building development, while in the case of AP04, an additional decision support tool for developing emission reduction strategies can be provided through knowing the portion of the anthropogenic and the biogenic part of CO_2 emissions in a high spatial resolution (neighborhood scale). In the case of AP09, users are not familiar with this kind of information, although it can provide highly useful information for the intra-urban variation of energy storage and release an urban variation of energy storage and release.

From the assessment of the **User Skill Level**, the only software that encountered the 'not responding' issue was AP01 concerning the ability to interpret the results however, to run the simulations there is a need to have expertise in commonly used GIS software. Another software with low levels of required expertise from the user is the AP02 which, in comparison with the competitors with the same target, in such case potential users should have expertise in remote sensing and implement the corresponding solution. Instead, using CURE AP02 even non-expert can easily run the tool and interpret the results. In most cases, specific expertise would be required in urban radiation and energy balance is needed for a correct interpretation of the results (AP03) as well as basic knowledge of CO_2 sources and sinks required for the correct interpretation of the results (AP04).

As far as **compatibility** criteria are concerned, most of the evaluations show that either the integration or combination of existing city data with CURE APPs is well addressed by the APPs evaluated. AP01 and AP02 have not provided accurate information. The AP03 and AP04 resemble similar performance to solutions available in the market. In the case of AP03, for best results use local data, but local data could be replaced by Copernicus data, if available. While the traffic data is the most essential input for AP04, besides building volume (local data), seasonal NDVI (Sentinel) and population density (Urban Atlas).

Finally, concerning the group of **Decision making-process**, the highest score was given to AP01 in terms of meeting the demand, due to the importance of accessing the heat load of cities along with other heat-related applications. Although AP03 and AP04 meet the existing demand it is mostly restricted to scientific users when exploring the urban energy balance. In combination with other CURE heat applications, they can also be useful for urban planners in the assessment of a city's heat load. The assessment of how the APPs translate evidence from data into action has shown that, except for the AP01, all APPs represent a limitation in this respect, but also the existing solutions. After exploring the price value of the evaluated apps, most of them have acceptable costs for end-users or even reasonably low and competitive (for users). Just the AP04 can only be implemented with flux tower data for calibration, however, the operation and maintenance of flux towers are expensive.

The highest score was given to the AP03, ENVI-met and AP04, and their main strengths are based on supporting urban planners in the decision-making process, the low level of required expertise to both run the model or interpret the results and the compatibility level accordingly.

Despite the strength in performance, ENVI-met reveals some limitations regarding compatibility, when integrating with commonly used data and tools and the benefits of combining existing city data and CURE data are covered.

Furthermore, there are no similar services available for delivering urban heat storage maps from satellite and other Earth Observation data. All efforts are at the moment on a research-level and the CURE AP09 will be the first to allow insights on the method transformation into a service.

2.3.2 Climate change adaptation

Within this group, a summary of the results concerning the following three APPs is provided. The results of the benchmarking are very dependent on the low level of technological maturity of some applications such as the cases of AP10. For the competition, there are few well established similar commercial solutions and services similar to AP05- Urban Flood Risk (UFR), usually based on hydrological modelling and sure many new services in progress of development. For example, the OpenFlows FLOOD by BENTLEY, Flood Modeller by Jacobs, MIKE by DHI or services provided by Waterman Group. The the two options assessed have been: Hydrodynamic modelling (e.g. HEC-RAS) and Regional Flood Susceptibility Index (FSI). In the case of AP06-Urban Subsidence, Movements and Deformation Risk (USMDR), competing for equivalent commercial service are uknown by service providers. Several European companies are providing MT InSAR services, e.g.: TRE-Altamira, e-Geos, SkyGeo, Sensar, Sarsense, Gamma RS, Planetek, NHazka, and several other start-up companies and institutions (BRGM, KIT, NGO, …). EGMS online visualization platform will not provide comparable functionality. As for the green roof potential (NBS), Green City and the development by Santos et al. (2016) (Santos et al., 2016) have been included in the assessment. Green City is an online tool developed by TerraNIS for the study, monitoring and management of urban vegetation and green areas in cities and to accompany them in their ecological transition. It provides a diagnosis of the vegetation, quantifies it and qualifies it considering biodiversity and well-being aspects. For that, the tool uses satellite images of different resolutions (Pléiades and Sentinel-2 images), open data (Open street map and other sources) and INSEE data (French National Institute for Statistics and Economic Studies). The processing of this data allows the calculation of different simple and synthetic indicators that can be displayed on a dashboard. It also allows for guiding decisions and selecting priority areas of action, by introducing target values for each indicator.

The general overview of the assessment is shown in Table 2:

	CLIMATE CHANGE ADAPTATION: NBS & FLOOD SUBSISTENCE									
CRITERIA	AP10	Alternative solutions		AP05	Alternative solutions		AP06			
	NBS	Santos T et al. (2016).	GREENCITY	Urban Flood Risk (UFR)	Hydrodynamic modelling (e.g. HEC-RAS)	Regional Flood Susceptibility Index (FSI)	USMDR	Copernicus EGMS[1]	ESA GEP (Geohazard Exploitation Platform)	Local ground (geotechnical) measurements
FUNCTIONALITY										
Information quality & Usage level	4	4	4	2	3	2	3	4	3	3
Added value provided by the application	1	1	1	1	4	4	1	4	2	2
TOTAL	5,0	5,0	5,0	3,0	7,0	6,0	4,0	8,0	5,0	5,0
USER SKILL LEVEL										
Technical expertise required by the user TO RUN THE MODELS, SIMULATIONS (Maintainability of the system)	2	2	2	1	1	2	2	1	1	1

[1] *It is not exactly an alternative, as we plan to integrate the EGMS data as an input for AP06 - now we are performing our own PS InSAR analysis)*

	CLIMATE CHANGE ADAPTATION: NBS & FLOOD SUBSISTENCE									
CRITERIA	**AP10**	**Alternative solutions**		**AP05**	**Alternative solutions**		**AP06**			
	NBS	**Santos T et al. (2016).**	**GREENCITY**	**Urban Flood Risk (UFR)**	**Hydrodynamic modelling (e.g. HEC-RAS)**	**Regional Flood Susceptibility Index (FSI)**	**USMDR**	**Copernicus EGMS[1]**	**ESA GEP (Geohazard Exploitation Platform)**	**Local ground (geotechnical) measurements**
Technical expertise required by the user TO INTERPRET THE RESULTS	2	2	3	3	1	3	1	1	1	1
TOTAL	4,0	4,0	5,0	3,0	2,0	5,0	3,0	2,0	2,0	2,0
COMPATIBILITY										
Integration with commonly used data and tools	2	1	2	2	1	1	2	1	1	2
Linking city data	3	3	3	3	1	1	3	1	1	2
Benefits of combining existing city data and CURE data	2	2	2	3	1	1	3	1	1	1
TOTAL	7,0	6,0	7,0	8,0	3,0	3,0	8,0	3,0	3,0	5,0
DECISION-MAKING PROCESS										
Meeting demand - a local authority that wants to know the	2	2	2	3	3	2	3	2	2	2

	CLIMATE CHANGE ADAPTATION: NBS & FLOOD SUBSISTENCE									
CRITERIA	**AP10**	**Alternative solutions**		**AP05**	**Alternative solutions**		**AP06**			
	NBS	**Santos T et al. (2016).**	**GREENCITY**	**Urban Flood Risk (UFR)**	**Hydrodynamic modelling (e.g. HEC-RAS)**	**Regional Flood Susceptibility Index (FSI)**	**USMDR**	**Copernicus EGMS[1]**	**ESA GEP (Geohazard Exploitation Platform)**	**Local ground (geotechnical) measurements**
current situation and make action plans										
Translating evidence from data into action	2	2	2	3	1	1	3	1	1	1
Price Value	3	3	2	2	2	3	2	4	3	2
TOTAL	7,0	7,0	6,0	8,0	6,0	7,0	8,0	7,0	6,0	5,0
TOTAL score	**23,0**	**22,0**	**23,0**	**22,0**	**18,0**	**21,0**	**23,0**	**20,0**	**16,0**	**17,0**

Table 2: Models/apps assessment of Climate change adaptation group

Overall, the results revealed that CURE APPs are positioned at a slightly superior level in comparison to other alternative solutions except for the AP10-green roof potential service in which, GreenCity is providing similar performance. In this regard, despite not being a tool focused on green roofs, in their diagnosis green roofs could also be included. Besides this, the tool includes the possibility to prioritize intervention areas thanks to the possibility of introducing target values for the indicators, which is something that could be included in CURE AP10.

Firstly, the results about **functionality** aspects show that the most efficient application is Hydrodynamic modelling (e.g. HEC-RAS) which provides higher precision than CURE AP05. While AP05-UFR shows a weakness in *the added value* provided by the application. The main strengths of the alternative solutions compared to AP05 relies upon that they are well-known in the consultancy business; some of them allow for modelling in very high spatial detail; and some of them are taking into consideration also the sub-surface runoff supported by sewage drainage in the cities etc. The AP06-Urban Subsidence, Movements and Deformation Risk (USMDR) is less mature in the market but most of the MT InSAR providers provide their online platform for the exploration of complex InSAR results with likely similar basic functionalities and specialized functions and visualizations depending on each service provider’s expertise and business model. Results revealed that the added value of tools such as AP10 is slightly recognized by urban planners and urban authorities however, in terms of *information quality* and usage level, the highest score has been assigned to the three apps evaluated for green roof potential.

From the assessment of the **User Skill Level**, high-level *expertise is required to interpret the results* by the end-users according to the assessment results of the three APPs of Urban Subsidence, Movements and Deformation Risk (USMDR) as well as the *maintainability of the systems* are very complicated. The CURE-AP05 (UFR) obtained a lower level of performance than the HEC-RAS hydrodynamic model.

As far as **compatibility** criteria are concerned, most of the evaluations show that either the *integration or combination of existing city data* with CURE APPs are well addressed by the APPs evaluated. Results point out that AP05 and AP06 are considerably outperforming the other applications; being HEC-RAS, FSI, Copernicus EGMS and ESA GEP tools those that received lower performance. Furthermore, the main strengths of the AP05 are as follows:

- It is based on Copernicus data – allowing easy replication for any Copernicus city and also in the future, as the Copernicus program guarantees harmonized data acquisition/production in the following years
- Running on DIAS – no demands on the user own processing infrastructure
- Based on satellite imageries – allowing to perform both historical analysis and rapid monitoring as a response to recent events

The integration with other common data in the case of AP6 regards Copernicus Urban Atlas EGMS, WSF datasets. Additional datasets depend on the technology provider. Regarding *linking data*, it shows that Urban Atlas may be replaced by a master plan after harmonisation into UA nomenclature, and ground motion measurements may be supplemented by a custom dataset if harmonized into EGMS-like format. As far as AP10 is concerned, its main weakness in compatibility criteria lies in the highly integrated with LST, imperviousness and NDVI data but it requires high-resolution DSM data, while GreeCity allows the integration with Sentinell and Opendata from cities. The weakness of the tool evaluated by Santos T et al. (2016) is related to not integrating with commonly used data is not provided. Only VHR and LiDAR are used.

Similar to the previous criteria, concerning the group of **Decision making-process**, the highest score was given to AP05 and AP06 in terms of *meeting the demand* and *translating evidence from data into action*. The potential contribution of AP10 to these two criteria is limited. AP10 is more specific, and it is focused on the greening potential of roofs, excluding those that could not been transformed into green roofs for different reasons (slope, load limits, etc.). Meanwhile, City Green is focused on the diagnosis of the green areas of the city (that could also include green roofs, but not sure about this), but does not calculate its greening potential. By introducing target values the user can identify the areas that don't reach the values in order to prioritize the interventions, but this does not mean that reaching the objective will be feasible. Furthermore, the service is only available for Toulouse it is necessary to contact them to include new cities. After exploring the price value of the evaluated apps, most of them have acceptable costs for end-users or even reasonably low and competitive (for users). The cost of AP10 is acceptable for end-users as long as the city would have a LiDAR/DSM; in the case of AP05 and AP06, it is too early to provide an assessment from the end-users however it is worthy to note that the available solutions in the market have acceptable costs for end-users.

Overall, within the field of Green Roof Potential, both CURE AP10 and the existing services are resembling similar performance values. We can assert that GreenCity and CURE resemble similar advantages except for the criteria of user skill expertise, in which GreenCity just demands a basic level of expertise. In this case, GreenCity offers a wider scope because it provides all types of existing vegetation although CURE AP10 is more focused on evaluating the potential for vegetation.

Despite the limitations of AP05-Urban Flood Risk regarding the criteria functionality and user skill level required, it is achieving remarkably higher performance in the aspects of compatibility and decision-making process. Concerning compatibility, CURE will further advance on both approaches the flood risk management:

- CURE data can serve as an input for physical models (such as ISIS, MIKE FLOOD and others) for example for digital elevation models and the rainfall data under climate change projections.
- Satellite images from Copernicus are the base for flooding mapping.

Although the HEC-RAS, which provides a higher precision than CURE AP05, and the Regional Flood Susceptibility Index (FSI) are performing better in functionality and user skill level respectively.

Similar to AP05, the great advantages of the Urban Subsidence, Movements and Deformation Risk (AP06-USMDR) in the CURE system rely on the decision-making process and compatibility. Although it can not offer a competitive price to the users, AP06 show an important advantage in linking city data and provides remarkable benefits regarding the combination of existing city data and CURE data. Furthermore, there are no competing equivalent commercial service to AP06. Several European companies are providing MT InSAR services, e.g.: TRE-Altamira, e-Geos, SkyGeo, Sensar, Sarsense, Gamma RS, Planetek, NHazka, and several other start-up companies and institutions (BRGM, KIT, NGO, …). EGMS online visualization platform will not provide comparable functionality.

2.3.3 Health, Air quality and thermal comfort

The assessment questionnaire for the third group of APPs, 'Health, Air quality and thermal comfort' was filled out by partners – service providers – involved in the development of AP07, AP08 and AP11 and their responses are shown in Table 3. The assessment of this third group was developed through observing available solutions in the market providing Air Quality and Thermal Comfort maps as well as Air Pollution Health Risk Assessment.

Within the field of Air Quality, most EU air quality products are regional scale or courser (e.g. CAMS). Local air quality services are typically also local in areal coverage and therefore for most CURE cities not available for comparison. However, the assessment covered three alternative solutions: traditional measurements, high-resolution air quality models (such as those provided by ADMS-Urban[2] and uEMEP[3]) and lower resolution models or open-source models (CTM such as CAMS/land-use regression models). ADMS Urban software (resembling TRL9) provides a similar consultancy service to AP07 however, as mentioned by the service provider, *"We have somewhat more experience with Copernicus data as a driver for the models (important for a pan-European service), and we have more connections with the market in Eastern EU (important for services for urban, regional and national authorities in that region)."* (D6.1). Many open-source air quality models exist (e.g. Aermod) that could be used in combination with the CAMS data by local authorities or research institutes[4]. In the case of Thermal Comfort, Urban thermal comfort expressed by WBGT can be either measured or modelled. In prevailing EU projects such as Climate-fit.City and RAMSES, experience has been gained on the use of models (such as UrbClim) for simulation of thermal comfort using this indicator. However, at a business level, there are a few commercial software packages such as ENVI-met and FLUENT that can deliver similar high-resolution thermal comfort maps for buildings/city quarters and that are used by consultancy firms/research institutes in projects for urban authorities. These two software were benchmarked as well as 'heat stress measurements' (e.g. citizen science campaigns). Some consultancy companies/research institutes make use of high-resolution remote sensing imagery, combined with empirical relations or measurements, to estimate spatial heat stress patterns in cities (e.g. (Koopmans et al., 2020)). With such a service, scenario analyses are not possible and it is difficult to validate against measurements. Most probably there are other services in development since this is a growing market, but none

[2] CERC > Environmental software > ADMS-Urban model

[3] EMEP Home

[4] For detailed information and competitors and the market situation: see reports of the EU H2020 AirQast project.

of these has the direct links to Copernicus and the scientific background that CURE service AP08 has. As for the air pollution health risk, there are two other known[5] assessment tools on a regional level, Aphekom and EcoSense (based on (Anenberg et al., 2016)).

[5] We refer to below tables for comparison of the three systems (Anenberg, S. C., Belova, A., Brandt, J., Fann, N., Greco, S., Guttikunda, S., … Van Dingenen, R. (2016). Survey of Ambient Air Pollution Health Risk Assessment Tools. Risk Analysis, 36(9), 1718–1736. doi:10.1111/risa.12540).

Health, Air quality and thermal comfort

CRITERIA	AP07	Alternative solutions			AP8	Alternative solutions			AP11	Alternative solutions	
	UAQ	Measurements	ADMS-Urban and uEMEP as example	CTM such as CAMS / land-use regression models	UTC	ENVI-met[6]	FLUENT[7]	Heat stress measurements	Evaluation of Air Pollution (EVA model)	Aphekom	EcoSense
FUNCTIONALITY											
Information quality & Usage level	4	3	4	2	4	3	3	3	4	3	4
Added value provided by the application	4	4	4	1	4	3	1	3	3	3	2
USER SKILL LEVEL											
Technical expertise required by the user TO RUN THE MODELS, SIMULATIONS	4	2	4	4	3	3	2	2	4	4	4
Technical expertise required by the user TO INTERPRET THE RESULTS	3	3	3	3	2	2	2	2	2	2	2
COMPATIBILITY											

Integration with commonly used data and tools	2	1	2	1	1	1	1	1	2	2	2
Linking city data	4	1	4	4	3	2	2	1	3	1	1
Benefits of combining existing city data and CURE data	4	1	4	3	3	3	3	1	1	1	1
DECISION-MAKING PROCESS											
Meeting demand	4	1	4	1	4	3	3	3	4	1	1
Translating evidence from data into action	3	4	3	3	1	1	1	4	3	1	1
Price Value	4	3	4	3	4	4	4	4	3	4	4
TOTAL EVALUATION	36,0	23,0	36,0	25,0	29,0	25	22	24	29,0	22,0	22,0

Table 3: Models/apps assessment of Health, Air Quality and Thermal Confort group

[6] https://www.envi-met.com/buy-now/

[7] https://www.ansys.com/products/fluids/ansys-fluent

Overall, the three CURE apps resemble higher performance than the compared solutions except for the Air Quality Maps provided by ADMS-Urban whose performance is similar to the CURE APP in this field.

Results derived from the assessment of **functionality** show that three CURE apps achieve the highest performance in terms of information quality, usage level and added value. *Information quality* assessment shows that three options, including AP11, provide a quite high level of quality of information as well as its usage level as long as good data input is available. In this sense, AP07 provides an advantage if good data is available and allows the user an assessment beyond the current-day situation as well as sector contribution or scenarios. At this moment, there are no services that model the air quality at a street-level scale throughout Europe. There are however services relying on modelling at a lower resolution, and services that rely on air quality measurements. A pan-European high-resolution (street-level) modelling service would moreover provide the ideal tool to compare cities with each other.

The thermal comfort maps provided by AP08 are used as input for climate assessment and adaptation plans in several cities throughout Europe and like AP07, scenario analysis is possible. In the case of air pollution, EVA model (AP11) has a competitive advantage stemming from a solid recognised *added value*. It has been used by Danish authorities, and urban planners for policy applications, and has been peer-reviewed. Denmark is in the unique position of having a central register with information regarding address, sex and age for all persons in the country. The CPR dataset (Central Personedata Register) is set into coordinates by matching the dataset with the national register of addresses and making it into 1 km x 1km grid cells. Similarly, the added value of CURE app for air quality is internationally recognised by the air quality modelling community; used by national, regional and urban authorities in many countries BE, IE, HR, SK, HU, PL.

The added value that Urban Air Quality Map as a consultancy service provides lies in the volume of local datasets that the client has. Some clients prefer to use their local datasets and others neither have enough sufficient local datasets nor resources:

- Clients that prefer to use their local datasets, do not need CURE AQ application:
  - European national / regional or urban authorities (e.g. the UK, France, Belgium, the Netherlands, Germany, Sweden, Finland ….) have many years' expertise in producing air quality maps using AQ models for their region and cities. More recently, at high resolution as AP07 proposes. These models are often tailored to use the local datasets (e.g. traffic data, fleet composition) and therefore provide much better quality than the CURE AQ application. In some cases, the authorities run the models themselves, in other regions the work is often subcontracted out (as frameworks or contracts) to local experts: at universities, research institutes or consultancies.
  - Cities/regions / countries that do not use a high-resolution AQ model but do have a lot of detailed information (traffic flows, fleet data, information on residential sources). For these stakeholders, the quality of an AQ application based on the local data will always outperform the AQ model solely based on Copernicus data.

- The third group of stakeholders are those cities/regions / countries lacking sufficient local datasets and resources (economically and technically) to prepare urban scale maps, to which we aim this CURE service.
- A final group of potential clients considers the institutes willing to provide a pan-European service. At this moment, there are no services that model the air quality at a street-level scale throughout Europe.

As for the Thermal Comfort Map, the added value is built on its high applicability, low-cost price and VITO track record. Especially the knowledge on the establishment of service in this respect might be useful for CURE. Although ENVImet and FLUENT are well-known in the consultancy business and they allow for a lot of detail in the input data (lots of scenario options), they do not allow to model large areas and make use of idealized settings, difficult to validate against measurements.

User Skill Level criteria play an essential role in the case of Urban Quality Map although with a similar performance to the ADMS-Urban and uEMEP high-resolution air quality model or the lower resolution models. The need for skilled personnel on running the model as well as to interpret the results is not considered critical for using the AP07. Although, in some cases, the authorities run the models themselves or the work is often subcontracted out (as frameworks or contracts) to local experts: at universities, research institutes or consultancies. While in the case of AP08 and AP11, a specific level of expertise would be needed since some of the results will need to be explained by the researchers behind the model. In this aspect, the CURE apps do not show higher performance than similar commercial services.

Within the **compatibility** criteria group, in comparison with other aspects, *integration with commonly used data and tools* criteria has overall been rated as critical by service providers; it mostly depends on the technology provider except for the thermal comfort software tool. The Urban Air Quality Map considers the integration with CAMS and it is highlighted that there is not a lot of commonly used data for urban air quality, it is just focused on integration regarding background concentrations. Moreover, many open-source air quality models exist (e.g. Aermod). These models could be used in combination with the CAMS data by local authorities or research institutes. It however requires a lot of experience with big data and (linux) programming to get these models up and running, leading to high costs. The results revealed that in air quality and thermal comfort, most tools evaluated resemble high rates of performance regarding *linking data* and *combining existing city data and CURE data*. The AP07 helps develop monitoring targets and AP08 offers through scenario analysis some insight into the direction the city is going showing better performance than ENVI-met and FLUENT tools.

Finally, as far as the group of **Decision making-process** is concerned, the three APPs received the highest score with regard to *meeting the demand*. The urban quality air map, although similar to uEMEP models, is applied across Europe for DG ENV projects. The thermal comfort service covers the whole city and can assess different adaptation options but this appreciation refers to a local authority standpoint that wants to know the current situation and make adaptation action plans. The EVA model provides the city of Copenhagen and Aarhus (Denmark) with annual or biannual reports from the results of the model produced by Aarhus University while it is unknown if Aphekom and EcoSense are outperforming EVA in this criteria. The assessment results of how the APPs *translate evidence from data into action* revealed that all Air Quality APPs resemble a good performance in this respect, cities are using the model data to adapt specific plans, although they do not reach out to citizen science campaigns proven to initiate behavioural changes. However, in the case of thermal comfort assessment, there is not enough evidence on the fact that cities do have heat action plans so, it is too early to assert that the CURE AP08 supports translating evidence from data into action even the other models such as ENVImet or FLUENT. We can only expect to see implementation in 3 to 5 years. After exploring the *price value* of the evaluated apps, most of them have acceptable costs for end-users or even reasonably low and competitive (for users). Although the price is often an issue when initiating a project, either AP07 or AP08 have been already sold to urban authorities but similarly to the ADMS-Urban and uEME models. While lower resolution models (e.g. CTM such as CAMS) are offered as a free service, there exist some limitations in what can be achieved for urban authorities. The ENVI-met and FLUENT tools are considered more expensive to set up and run. As for the Air Pollution Health Risk Assessment Tools on a regional level, in the case of the EVA model, price value is not a competitive advantage (cost is acceptable for users) while the costs of Aphekom and EcoSense are reasonably lower.

Overall scores do not reflect the capabilities and limitations of each software tool, however, some competitive advantage can be envisioned. Having evaluated the total results of the scores assigned by the experts, at Air Quality modelling, the highest score of performance was given to the CURE Urban Air Quality as well as to ADMS-Urban and uEMEP, while the lowest score was given to traditional measurements. The main strength of AP07 compared to the others lies in the fact that there are no services that model the air quality at a street-level scale throughout Europe. There are however services relying on modelling at a lower resolution, and services that rely on air quality measurements. Both types of services however often fail to incorporate the street canyon contributions, which are important for the population exposure. A pan-European high-resolution (street-level) modelling service would moreover provide the ideal tool to compare cities with each other and the institutes willing to provide such a pan-European service are targeted by the CURE app. Despite the strength in performance, three apps reveal some limitations when integrating with commonly used data and tools.

In thermal comfort assessment, the highest score was given to the CURE AP08 which performs better than ENVI-met and FLUENT in functionality and compatibility criteria. and their main strengths are based on supporting urban planners in the decision-making process, the low level of required expertise to both run the model or interpret the results and the compatibility level accordingly.

Results revealed that the EVA model outperforms Aphekom and EcoSense in functionality, compatibility and decision-making process groups of criteria while showing similar rates at the user skill level, in all of them the results will need to be explained by the researchers behind the model. In the field of health risk assessment there exist other recent approaches. Demographic data and life expectancy can be taken from Eurostat (population by age and sex, and life expectancy by age and sex), and the mortality data can be taken from WHO (European detailed mortality database). The exposure-response relationship and the population at risk can be selected by following a recommendation from the Health Risks of Air Pollution in Europe (HRAPIE project - WHO). Quantifications of health impacts are done individually for these air pollutants, and they cannot be added together, as they exhibit some degree of correlation, positive or negative. For example, when adding together the values for PM and NO, this may lead to double counting of the effects of NO up to 30 %. These quantifications can then be directly converted to population exposure and premature deaths or years of life lost, **but this does not provide a quantification of the health and economic impact**. There is also a recent study funded by Public Health England (PHE) which has used a microsimulation model to produce longitudinal projections for the UK, **but is not city-specific** and only looks at PM2.5 and NO2, **hence lacking other crucial pollutants**. This study used a dynamic microsimulation model to predict the future health and economic impact of the air pollutants PM2.5 and NO2 by the year 2035. The **microsimulation method** is an advanced method for modelling chronic diseases because of its capacity to simulate entire populations at an individual level over a lifetime. The microsimulation model can be expanded to include additional pollutants and different populations **but further work would be needed to develop the model.**

2.4 Limitations of the results

The results of this research are limited to the evaluation provided by service providers taking part in the CURE project. The scoring system has provided the baseline for the evaluation and it has been based on the data gathered in previous WPs of the CURE project. Additionally, some initial results are derived from testing the tools in the cities involved in the project so, the maturity level of some of them is relatively low to develop an exhaustive analysis of benchmarking. Moreover, this research investigates the performance of software tools supporting urban planners and scientific personnel in developing the models on the 11 aspects covered by the CURE project. We are not providing how they are resembling performance in other contexts. It is worth noting that the assessment provided by the respondents is based on subjective opinions, there has not been completed with external documents or analysis of the same tools made from consultancies or research centres.

Nonetheless, the benchmarking results are limited to evaluating the performance of the tools dealing with a more user-oriented perspective therefore, further research could be developed to integrate different testing exercises or experiments aiming to gain objectivity of the evaluations as well as including more service providers or end-users to verify results.

3 ECONOMIC FEASIBILITY

3.1 Objectives

The objectives of conducting an economic feasibility assessment of the CURE services&system (hereafter referred to as CURE) are twofold.

First, to assess the cost and benefit aspects of CURE, to provide an estimate of costs of operating CURE and serving cities and towns across EU. For simplicity we use 100 EU cities as a target for our calculations. Benefit aspects are based on an impact pathway assessment, hence a narrative approach. Estimates of 'What's at stake' in terms of future investments into actual climate adaptation measurements will be used to provide an overview of the potential benefits in 'an order of magnitude' approach in our attempt to valorise the CURE services and system.

The second objective of the economic feasibility is to assess the strategic aspects of CURE and to provide for a gap analysis and potentially scenarios for an integration of CURE cross-cutting services into the Copernicus family.

3.2 Assumptions and considerations

The economic feasibility assessment is based on the following assumptions: A, B and C as described below.

A	CURE applications
›	The APPs developed in CURE can be regarded as core services
›	The APPs can be regarded as building blocks to develop more value-added and more advanced and interdisciplinary cross-applications and modelling tools that can be facilitated based on the access to the CURE core services. For instance, to improve strategic decision making related to implementing climate adaptation measures
›	We are assuming that CURE core services will be freely available, as is the case for other Copernicus core services
›	The 11 CURE core services should be regarded as Proof-of-Concept services and it is likely there are gaps in relation to current and future needs of the Urban demand for climate services, for instance to develop more relevant NBS (nature-based solutions)
B	First and second order of beneficiaries

<table>
<tr><td colspan="2">

› First order of beneficiaries are Downstream service developers

› Second order of beneficiaries are the Cities and city stakeholders since they benefit from the value-added service to be developed from the CURE core services

› It is not expected that cities or city stakeholders will be direct users of the CURE system

› It is assumed that the CURE system over time will develop to incorporate new cross-cutting services in response to market and cities needs

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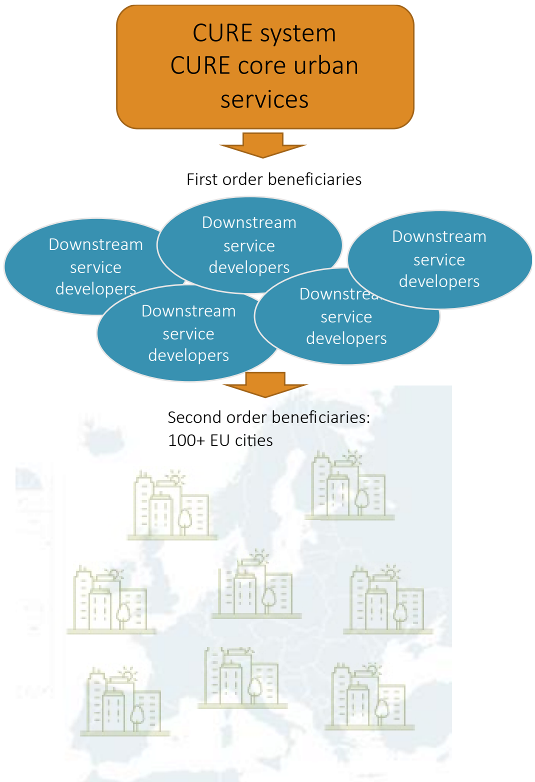
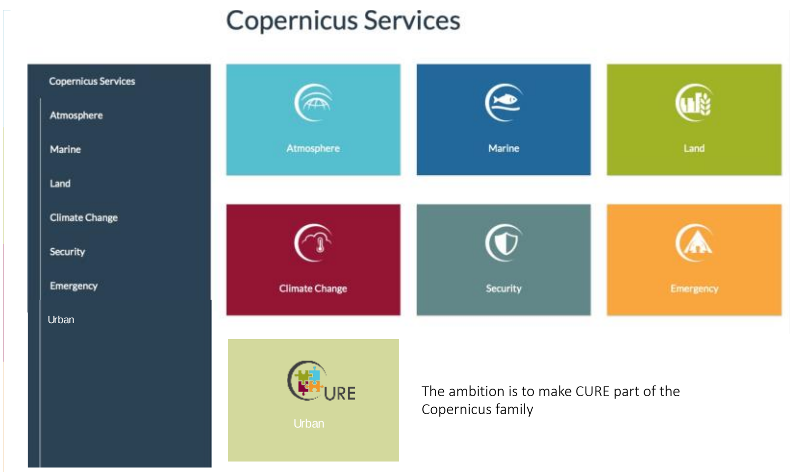


</td></tr>
<tr><td>C</td><td colspan="2">Future financing of CURE</td></tr>
<tr><td colspan="2">

› Financing of CURE core services, e.g. running the CURE system and the core services, will be done similar to other Copernicus core services, e.g. by public funding

› It is assumed that CURE one way or another will be part of the Copernicus family in the future

</td><td>



</td></tr>
</table>

3.2.1 Scope and limitations

Although the CURE portfolio of applications covers both climate mitigation, climate adaptation and health in cities, the focus in this assessment will be on the two latter. This is due to: 1) the CO2 APP included in the CURE project is still in an early research phase, 2) that the main investment for the cities into mitigation measures (e.g. CO2 reductions) are related to investments into a switch in energy production towards renewable energy and green transport. The CURE service portfolio only offers limited added value in this regard.

3.3 Approach and methodology

Our approach has been based on a number of tasks and interactions with the other WPs of the CURE project.

- Using results from other WPs, notably WP3 and WP5
- Using the results of Task 6.1 Scenarios and D6.1
- Developing the methodology for costs and impact assessment
- Data collection and analysis
- WP 6 coordination and discussion meeting
- Validation process with APP and system developers

3.3.1 Main inputs from T6.1

- Criteria for upscaling
- The 3 scenarios
- First round of cost collection of individual APPs

3.3.2 Methodology of costs and impact assessment

Assessment of operating cost of CURE component

Based on two rounds of data collection from CURE APP developers estimates for both CAPEX and OPEX was obtained. Based on the experience in developing the APPs, the idea for the costs estimate was to obtain an idea of the main cost items, e.g. to get an idea of the upscaling costs, e.g. from a few cities to a hundred cities across Europe and to get an overview of the 'economics of scale' potential.

Valorisation of CURE cross cutting service

It is always very difficult to assess the impact or added value of a service that only indirectly adds value to a given problem. That is the case with most EO based services. An EO based map can pinpoint to a given problem and provide a quicker and more accurate and holistic overview of a given issue, e.g. an oil spill, hot spots of poor air quality, or high areas of thermal discomfort, etc. Therefore, the type of impacts to be derived from using EO based services usually falls into one of the following categories: a) operational cost savings (as opposed to in situ data collection that is more time consuming to collect); b) better quality data as an EO image can give the full picture and are based on 'fresh' data, often used in combination with in-situ data and other local data such as demographic and socioeconomic data that improves the basis for making the best possible decision for how to solve a given issue, e.g. investment decisions and prioritisation concerning for instance how to limit UHI effect or how to improve air quality.

Therefore, we have applied a certain logic or basic assumption for the impact pathways of CURE.

CURE cross cutting services will improve the basis of which decision making related to climate adaptation measures can take place, by providing more accurate data, analysis and modelling of different climate adaptation interventions.

Climate adaptation will require billions of Euro's in investments in the coming decades and the risk of mal-investments is high and can only be minimised by having the best possible information, and modelling tools to improve the quality of decision making in order to make the optimal climate adaptation investment decisions.

> Adaptation investment needs in the EU are estimated to range between EUR 35 billion and 500 billion annually, the large variation reflecting different underlying assumptions and methodological approaches . *(European Commission 2017)*

It is impossible to give an exact estimate of how much CURE service will improve the quality decision making related to selecting the most optimal climate adaptation measures for the city and thereby decrease the risk of mal-investments. It will also vary according to what other data is available and according to the type of measure or intervention in question. We reckon it could be anything between 1 ‰ to 10%.

Instead, we have collected narratives and provided rough estimates for what is at stake in terms of climate adaptation investments in Europe over the coming 20-30 years in selected sectors.

3.3.3 Data collection and analysis

A detailed approach for data collection is provided below.

Costs data for CURE APPs	
Nov-Dec 2020	Data collection using a questionnaire among CURE APP developers in connection with Task 6.
Feb-Mar 2022	Updating of costs figures among CURE APP developers including additional questions (
Mar 2022	Collection of cost data for CURE system
Climate adaptation investment costs	
Literature review Jan-May 2022	› Feyen L., Ciscar J.C., Gosling S., Ibarreta D., Soria A. (editors) (2020). Climate change impacts and adaptation in Europe. JRC PESETA IV final report. EUR 30180EN, Publications Office of the European Union, Luxembourg. https://ec.europa.eu/jrc/sites/default/files/pesetaiv_summary_final_report.pdf

	› EEA Report No 12/2020: Urban adaptation in Europe: how cities and towns respond to climate change › European Commission. (2017). Climate mainstreaming in the EU budget - Preparing for the next MFF: Fina report. https://op.europa.eu/en/publication-detail/-/publication/1df19257-aef9-11e7-837e-01aa75ed71a1 › EEA Report No 2/2017 Financing urban adaptation to climate change › COACCH: The economic Costs of Climate Change in Europe › Climate-fit.city: D6.4 Socio-economic Impact assessment (II) › https://www.hofor.dk/baeredygtige-byer/vi-skaber-baeredygtige-byer/klimatilpasning/ › Region of Copenhagen: Climate Strategy https://www.klimatilpasning.dk/media/1265668/regionh_klimastrategi.pdf

There is only scarce information available specifically for cities on climate adaptation investment costs, wherefore we decided to include concrete local examples and use these as basis for extrapolation.

3.3.4 WP6 coordination and brainstorming sessions

WP6 Task 2 Benchmarking and Task 3 Economic feasibility have been active since January 2022, with 6 months to deliver the current deliverable D6.2.

The team around these 2 tasks includes representatives from VITO, Tecnalia, CWare (lead), FORTH, UWE, GiSAT.

WP 6 Coordination meetings has been held on a regular basis every 4-6 weeks during the first semester of 2022 via Teams meetings.

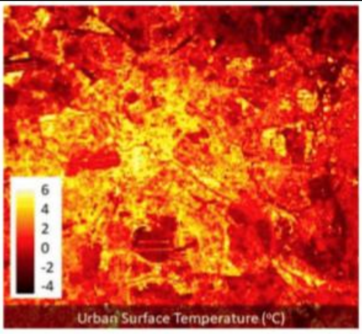
3.3.5 Validation process

The validation process included, firstly, validation of cost figures submitted by the individual service providers for the 11 CURE applications. Secondly, for the CURE service costs. Validation of the approach and results of the economic feasibility has likewise been validated internally to the team.

3.4 CURE APPs overview

APP01	Local scale surface temperature dynamics

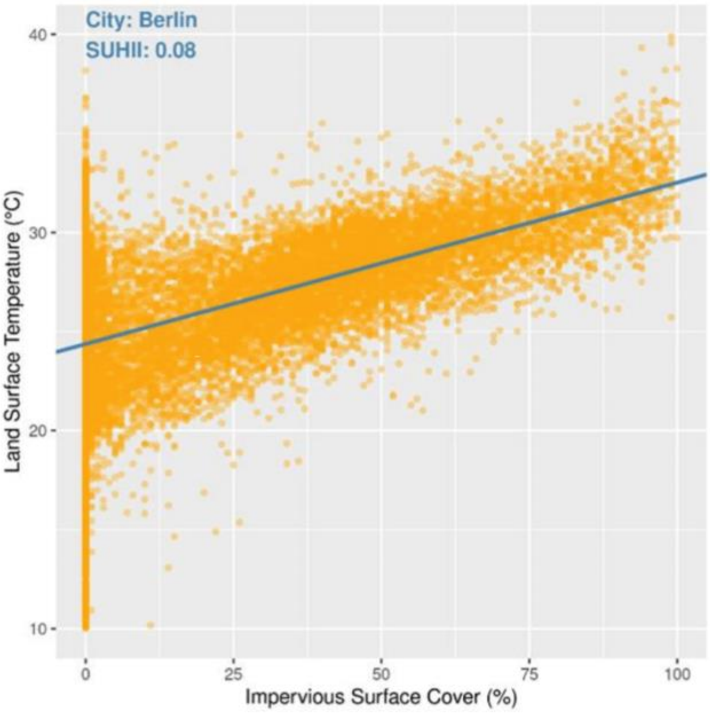
The surface temperature is one of the most important parameters in the physical processes of urban surface energy, water balance and the land-atmosphere exchanges. It constitutes a valuable information source for the understanding of the natural and human components of the Earth system. In this context, the anticipated application will be utilized in all urban areas involved in the CURE project, leading to frequent local scale surface temperature estimations.



Local scale urban surface temperature for Berlin corresponding to 24 July 2019, 21:26 local time, as derived from AP01

APP02	Urban Heat Island effect

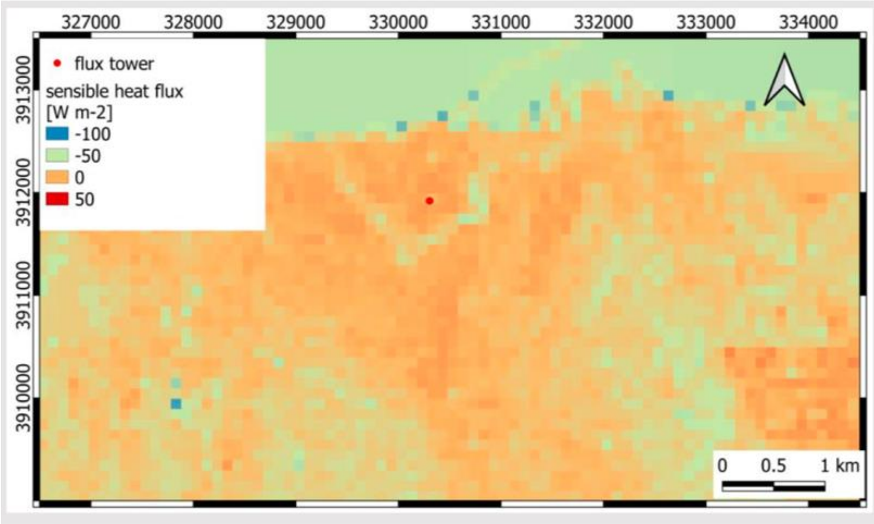
An UHI occurs, when a city experiences much warmer temperatures than nearby rural areas. Warmer air caused by UHI increases the heat load stress of urban residents, as well as the energy consumption and associated greenhouse gas emissions. Interpretation of Surface Urban Heat Island Indicator (SUHII) values allows to track temporal and diurnal susceptibility to urban heat stress. Identifying UHIs can contribute to the effective evaluation of potential heat risk.



Relationship between impervious surface and LST for Berlin. The blue line is a linear model fit, based on which the SUHII is derived.

APP03	Urban heat emissions monitoring

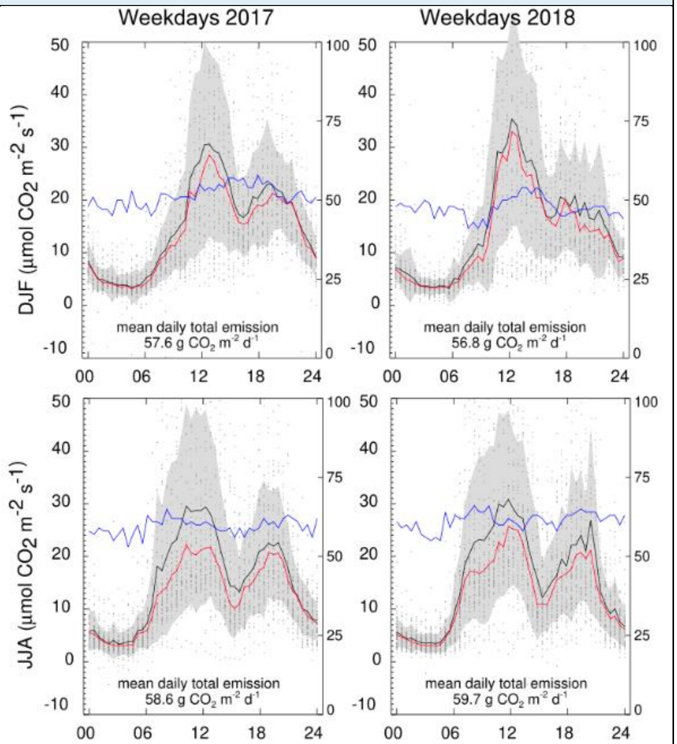
Urban heat emission refers to the turbulent sensible heat flux, i.e. the heat exchange between the urban surface and the atmosphere. The sensible heat flux defines the amount of energy that is available for heating the urban atmosphere, which is strongly modified by the properties of the surface and the input of heat by human-related activities. The localization of hotspots of high heat emissions will help urban planners to optimize the adaptation strategies, considering also heat stress, urban green space and building development.



The calculation output of sensible heat flux maps for CURE in a 100 m x 100 m grid for a day-time and a night-time situation of Heraklion city (Coordinates: UTM 35N).

APP04	CO2 emission monitoring

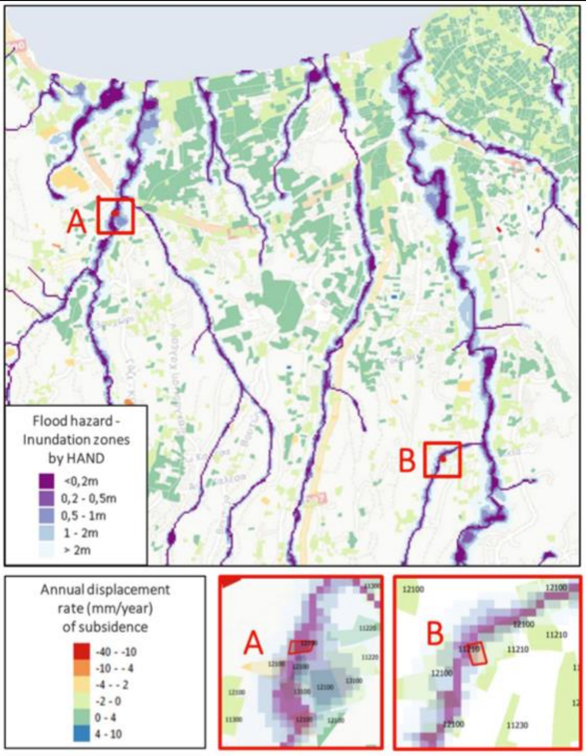
In this CURE application, the CO2 emissions are partitioned into an anthropogenic (traffic, heating/cooling) and a biogenic component (urban green space). Spatial planning strategies have an influence on the urban form, and consequently affect CO2 emissions through changes in traffic patterns, energy consumption, and location and extent of urban green areas. Knowing the portion of the anthropogenic and the biogenic part of CO2emissions in a high spatial resolution (neighbourhood scale) will provide urban planners with an additional decision support tool for developing emission reduction strategies.



The mean diurnal courses of CO_2 emissions for weekdays measured at the HECKOR Heraklion flux tower, including the mean (black line), the median (red line), the standard deviation (gray shaded line), and the number of available half-hourly records (blue line, right y-axis) for weekdays in the respective season, i.e. top: winter (DJF) seasons - bottom: summer (JJA) seasons.

APP05	Urban Flood Risks

Floods are the natural hazard with the highest frequency and the widest geographical distribution worldwide. Due to societal assets concentration in cities, flooding can cause major disruptions and lead to significant impacts on people, economy and environment. This application captures the multi-scale aspect of flood risk assessment providing relevant information and contributes to rapid flood monitoring. This service aims to support urban planners both during city preparedness and climate adaptation activities, as well as during emergency situations with information support to city response activities

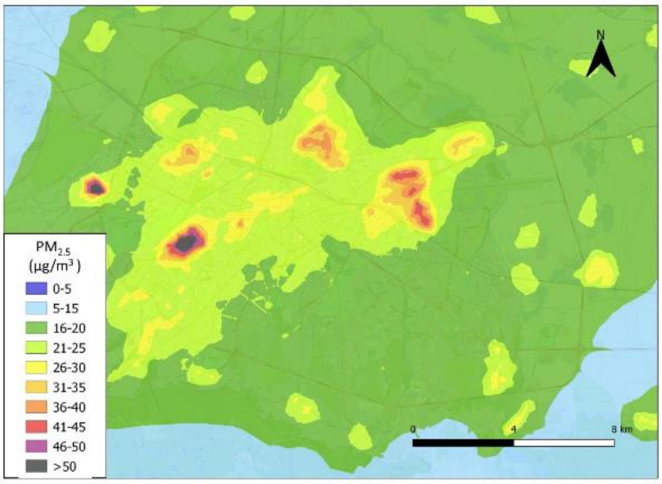


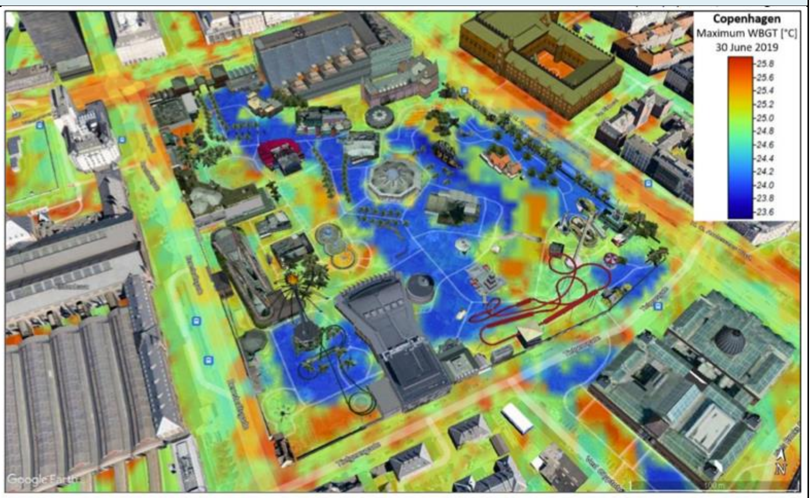
Combining information about flood and subsidence hazard – identification of urban blocks endangered by both flood and subsidence hazards.

APP06	Subsidence, movements and deformation risks

Ground and construction movements are responsible for hundreds of deaths and billions of Euros lost annually. In a more and more urbanized world, the threats of urban subsidence, slope instability and building or infrastructure deformations are also deteriorating due to the large increase in the number of extreme events related to climate change and the sub-optimal

The subsidence risk exposure evaluation for all urban blocks (left) and the exposure to land subsidence for a selected urban block (right).

<table>
<tr><td colspan="2">building and infrastructure maintenance. This application is utilized for subsidence risk assessment, coupling hazard monitoring with up-to-date assets information. The provided accurate assessment of threats and vulnerabilities is critical for urban planners to understand and manage the subsidence risk to the actual city assets</td></tr>
<tr><td>APP07</td><td>Urban Air quality</td></tr>
<tr><td colspan="2">Air pollution is one of the main environmental issues in urban areas and urban air quality is a multi-scale issue, since pollutant concentrations at street-level scale are influenced by regional (rural) background concentrations. Urban increments arise from local industrial and traffic sources, as well as an additional contribution from recirculation in street canyons. This application captures the multi-scale aspect by incorporating several models into an integrated model chain and provides street-level maps of NO2 concentrations for entire urban areas, which allow stakeholders to identify pollution hotspots in the urban metropolitan region and allows for the assessment of pollution reduction measures.


Annual mean $PM_{2.5}$ concentrations in 2019 in Sofia.</td></tr>
<tr><td>APP08</td><td>Thermal comfort</td></tr>
<tr><td colspan="2">Heat stress is an increasing problem in many European cities, having a negative impact on sleep, productivity, health and mortality of urban residents. Urban populations experience higher levels of heat stress (measured as Wet Bulb Globe Temperature or WBGT) than people in rural areas due to higher air temperatures,


Daily maximum WBGT in the Tivoli Gardens in Copenhagen on 30 June 2019.</td></tr>
</table>

lower wind speeds and higher levels of solar and thermal radiation. This CURE application will quantify and map human thermal comfort at a very high resolution for entire urban areas. This will allow urban planning and development stakeholders to identify hotspots and give them insight into the local variation of heat stress. Furthermore, the application will allow users to upload different land use scenarios and assess the effectiveness of adaptation measures.	
APP09	Urban heat storage monitoring
Observations of global temperature evolution indicate a pronounced air temperature warming, since an increase in the occurrence of heat waves and the UHI effects tends to exacerbate such warming. Among all the effects caused by the substitution of natural ecosystems for urban land-use, the most pronounced is the increase in the amount of energy stored in the urban canopy, which is much larger than in non-urban canopies. The slow release of this energy causes the UHI effect and it is therefore related to the energy efficiency and consumption in cities. In this framework, the CURE application will deploy various earth observation and in-situ data towards monitoring urban heat storage.	
APP10	Nature-based solutions
Nature-Based Solutions are gaining relevance for the enhancement of urban sustainability and resilience, given the increased evidence about a wide range of multiple environmental, climate and socioeconomic related co-benefits, which they provide. Specifically, green roofs could improve performance of single buildings, while generating at the same time important positive effects in public spaces at city scale. This application will allow urban planners to quantify maximum potential deployment of green roofs by assessing at city scale key enabling conditions for installation. Alongside, benefits related to key resilience challenges will be modelled and evaluated. Both outputs will inform local decision making by benchmarking alternative scenarios of green roofs potential.	
APP11	Health impacts (socioeconomic perspective)
The air pollution in the urban atmosphere consists of emission and transmission sources, each path influenced by different factors. In order to understand the magnitude of the negative impacts to people's health and subsequently the economy, this application will be able to provide cities with a detailed survey of air pollution and its sources to indicate how many people die prematurely due to air pollution and the associated costs for society. The results from this application can guide local and regional decision makers in their policymaking with sound economic estimations of costs due to poor air quality.	

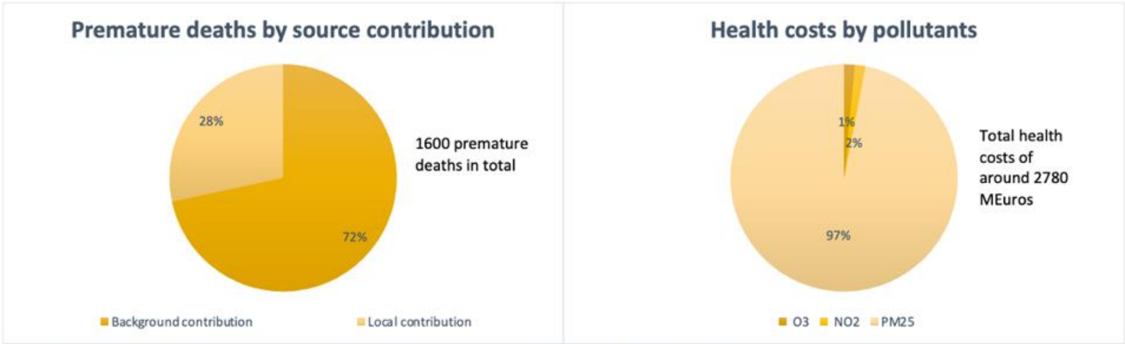
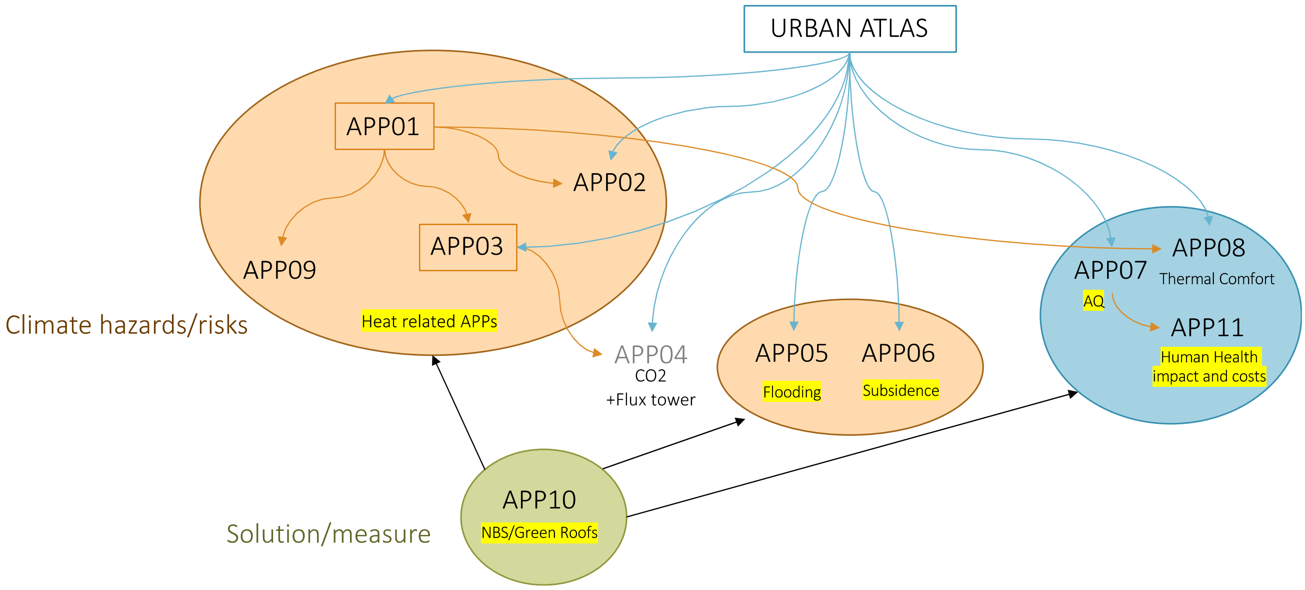


Figure 3 Sofia 2018. Left: premature deaths by source contribution. Right: health costs (MEuros) by pollutants.

The relations and interdependencies between the individual application are mapped in Figure 3-1 below. Most of the applications uses URBAN ATLAS as data source. Likewise, APP01 provides input to 4 other CURE applications. While the heat related applications and the flooding and subsidence ones are related to climate hazards, the air quality, thermal comfort as well as the health costs relates to health in cities. APP10, the green roof application provides solutions to climate adaptation measures.

Figure 3-1 CURE APPs – type of application and internal dependencies



3.5 Costs element of CURE

We asked the service providers to define type of upfront investments needed per city and type of operational costs, e.g. labour costs, data processing costs, data storage and data acquisition costs.

The full data set is inserted in Annex 1.

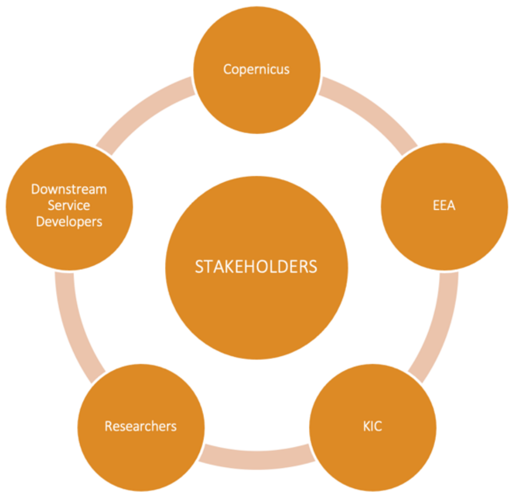
Roughly speaking, each APP costs in the order of 15KEURO per city in a pilot phase, while in an operational mode, serving 100 cities could be done for at least one-fifth of that price, e.g. around 150KEUR per APP in average and in round numbers. On average, the APPs will need updates every 5 years for each city.

	EUR/Y
CAPEX CURE APPs	300.000
OPEX CURE APPs	700.000
OPEX CURE system	100.000
Total costs	1.100.000

The operational costs of running the CURE system are estimated very modestly, to around 100KEUR per year.

3.6 Benefit elements and orders of beneficiaries

In assessing the benefits of CURE, we will distinguish between the benefits of the CURE system and the crosscutting applications offered through the CURE platform. It is important to bear in mind that we are assuming that the primary beneficiaries are the downstream service providers and other stakeholders or advanced users such as EEA, KIC, researchers, etc. The downstream service providers will then in turn develop tailormade and perhaps more advanced services to the urban market likely by integrating local data to add even further value to the final service provision. Figure 3-2, provides an overview of the type of benefits to be derived from the CURE systems and associated crosscutting applications for the first order of beneficiaries.



The benefits to the downstream service developers are:

- a one-stop shop for Copernicus urban data
- more developers attracted to use the CURE system and thereby the Copernicus data
- increased innovation and competition in downstream application development

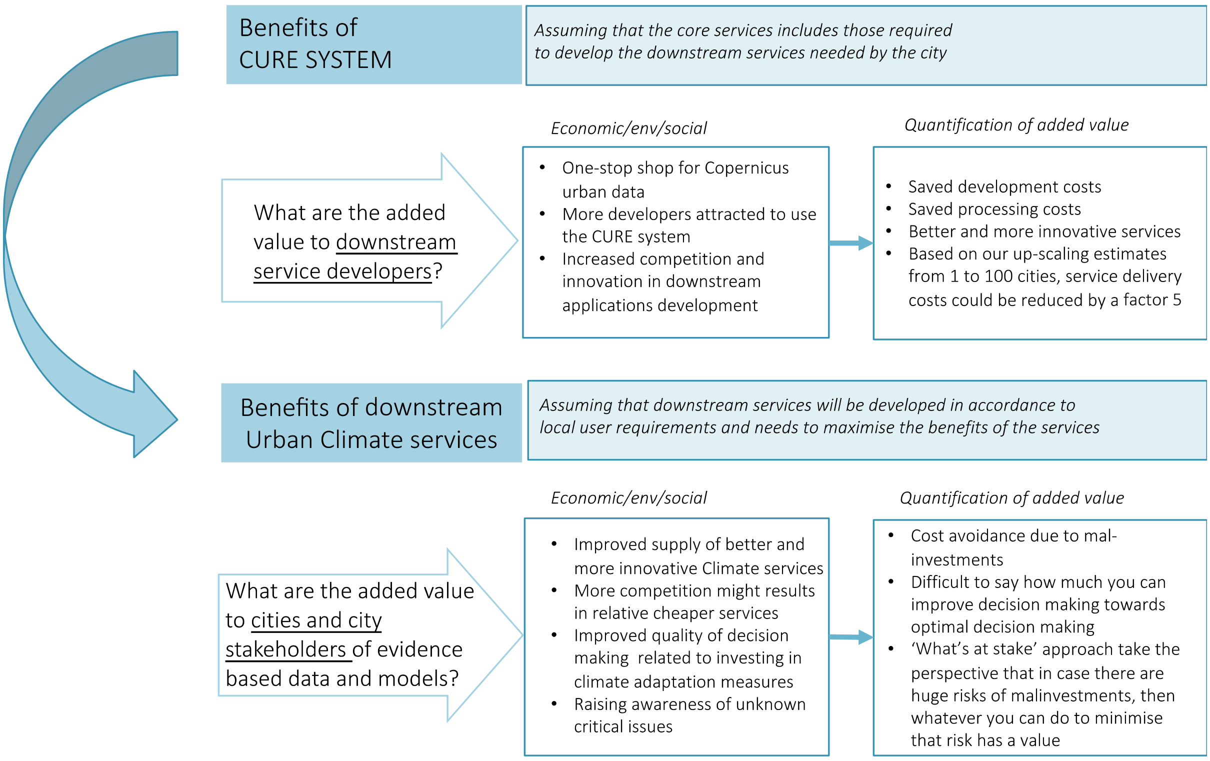
Quantification of such benefit items can lead to saved development costs for the downstream service developer, saved processing costs, better and more innovative services. Based on our up-scaling estimates for the CURE projects APPs, costs could be reduced by a factor of 5-10.

For the cities, and city stakeholders such as property developers, utility companies, etc., what we have referred to as second order beneficiaries, the benefit items have been identified as:

- improved supply of better and more innovative Climate services

› more competition among service developers might result in more cost-effective offerings
› improved quality of decision making related to investing in climate adaptation and mitigation measures as well as investment into healthy cities
› pin-point to unknown critical issues by identifying particular hot spots
› Provide the best possible evidence base for assessing the best option among different alternative measures

Figure 3-2 Benefits elements of the CURE system and downstream crosscutting applications



In the following sub-chapters, we will provide an overview and assessment of what is at stake for the cities.

3.7 What's at stake – Urban climate adaptation investments and healthy cities

The potential value of the CURE urban climate services must be seen in the perspective of the type of climate hazards facing European cities in the coming decades and in relation to the type of measures we need to put in place to minimize the impact of climate change in the cities. According to EEA (2020)[i] adaptation investment needs in the EU are estimated to range between EUR 35 billion and 500 billion annually, the large variation reflecting different underlying assumptions and methodological approaches.

3.7.1 Urban climate hazards – overview

Different European regions face different weather-related hazards in the coming decades. **The Atlantic region** (light blue) will have increased heavy precipitation events and river flow. They will experience increased risk of river and coastal floodings as well as damage risk from winter storms and a general increase in multiple climate hazards. On the positive side there will be less energy demand for heating. The **Boreal region** (dark blue) will also face increase in heavy precipitation events, decrease in snow, increasing damage risk from winter storms, decrease in energy demand for heating. The **Continental region** (green), will face increase in heat extremes and decrease in summer precipitation. Increasing risk of river floods and forest fires and increased demand for energy for cooling. The **Mediterranean region** (yellow) will face large increase in heat extremes, decreased precipitation, leading to increased risk of droughts, biodiversity loss, and forest fires. The scarcity of water will lead to competition between water users. Energy demand for cooling will increase, while there will be a decrease in energy production. Decrease in summer tourism, but potential increase during other seasons. Mortality from heat waves will increase. High vulnerability to spillover effects of climate change from outside Europe. In **Mountain regions** (purple), temperatures will rise more than European average. Glaciers will decrease in extent and volume affecting hydropower production negatively. Upward shift of plant and animal species, but high risk of species extinctions.

KEY MESSAGES (EEA 2020)

› All of Europe's cities are at risk from climate change, but the current and projected impacts vary depending on the hazards in the given location, combined with the city's exposure and vulnerability. Most impacts on European cities are likely to be connected to changes in climate extremes.

› European city representatives, consistently with scientific knowledge, identify heatwaves, heavy precipitation, flooding and droughts as the most severe current climate- and weather-related hazards, and expect the frequency and magnitude of these hazards to increase, affecting most areas of their activity — mainly the natural environment, water management, buildings and transport.

› While temperatures are projected to rise across Europe, cities in south-eastern Europe face the highest projected increase in the frequency of heatwaves combined with the lowest provision of green space and the most pronounced urban heat island (UHI) effect.

› Heatwaves claim more human lives than any other weather-related disasters, and UHI exacerbates the risks to vulnerable populations.

- Heavy precipitation events are projected to increase in frequency in the most of Europe. Their impacts are exacerbated by increasing surface sealing in cities and sewerage infrastructure that is often not fit for purpose.
- Large proportions of residential, commercial and other valuable types of land in European cities may be at risk of flooding due to their location in river or coastal floodplains. Around 10 % of the European urban population lives in potential river floodplains.
- The continuing development of urban floodplains combined with increasing river flows in most of Europe in the future is likely to magnify the already substantial impacts.
- The projected sea level rise is expected to raise the level of damage associated with coastal flooding and coastal erosion.
- By the end of this century, cities in southern Europe may experience droughts up to 14 times more intense than the worst episodes between 1951 and 2000, but water scarcity in cities in other European regions is also becoming a reality as a result of overexploitation of water resources and increasing frequency and magnitude of droughts.
- Urban sprawl and rural land abandonment exacerbate the risk of wildfires in hot and dry conditions predominantly, but not exclusively, in southern Europe. Nearly 70 000 urban residents live in areas that were directly affected by forest fires between 2000 and 2018, mainly in southern Europe.
- Windstorms are one of the most destructive natural hazards affecting the EU. The change in the frequency of windstorm events is uncertain as the climate changes, and urban areas remain vulnerable to impacts associated with damage to infrastructure and property.
- Climate change is conducive to the incidence of vector-borne diseases in Europe, in particular in the south. Higher urban temperatures improve the climatic suitability for vectors such as the tiger mosquito, contributing to the risk of disease spread.

In summary, the main urban climate change hazards are heat waves, heavy precipitation, flooding and droughts and due to the increase in both frequency and intensity it will have a huge impact on human health (mortality, productivity and wellbeing), the health of the natural environment (loss of biodiversity), water management (scarcity and quality of water), building and infrastructure (increased risk of subsidence, extreme heat affecting train tracks and roads, etc), and energy management (higher demand for air cooling).

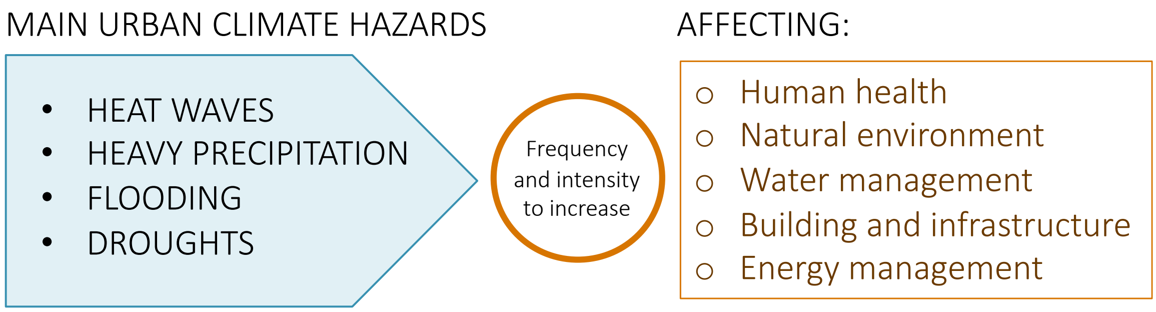


Figure 3-3 Main urban climate hazards and impacts

3.7.2 Urban climate hazards impacts and costs of adaptation

From the literature, EEA (2020), we have compiled the following table to get an overview of the type of measures and investments required over the coming decades to adapt to climate change and to build urban resilience. Most literature about adaptation costs assess the various economic sectors (agriculture, energy, etc), only few studies have made estimates particular for urban adaptation. All reports flag that huge uncertainties are associated with the provided numbers, hence, we can only talk 'orders of magnitude'. For each of the numbers provided in the table below it is clearly stated from which source the numbers have been extracted or in case of own estimates, the approach and assumption are clearly stated in indicated sub-chapters.

The first column lists the type of climate hazards as considered in the EEA report. In the current assessment, however, we focus on the first four hazards mainly since these are most relevant for CURE, but also because most data related to costs of climate adaptation investment are available for these categories. The second column 'Cost of no action' provides estimates of potential damages if no climate adaptation investments are made. The third column lists the type of measures needed to build resilience against future climate changes. The fourth column provides an overview of the level of investments needed over the next 15 years to implement the listed measures. The data here are very limited from official reports.

Figure 3-4 City of Hamburg, Green Roof Strategy

For heat we have based our estimate on the costs of greening, e.g. planting trees and installing green roofs since this is a strategy pursued my many cities as the cost-efficient approach to limit the UHI effect[ii] and to lower the ambient temperatures.

For 'heavy precipitation' we have used data from Copenhagen related to already planned and for some measures already implemented investments related to lowering risk from increased flash flooding and heavy precipitation. From these cost data and based on some assumptions, we have made an extrapolation for EU27.

Cities climate adaptation plans

For the cities, climate adaptation plans have to be ambitious yet realistic and has to provide solutions to the financial aspects as well. These guidance principles are clearly stated in the Climate Adaptation Plan for Copenhagen, notably the point of avoiding mal-investments, the holistic approach and that professional analysis is required, and investments should be returning green benefits.

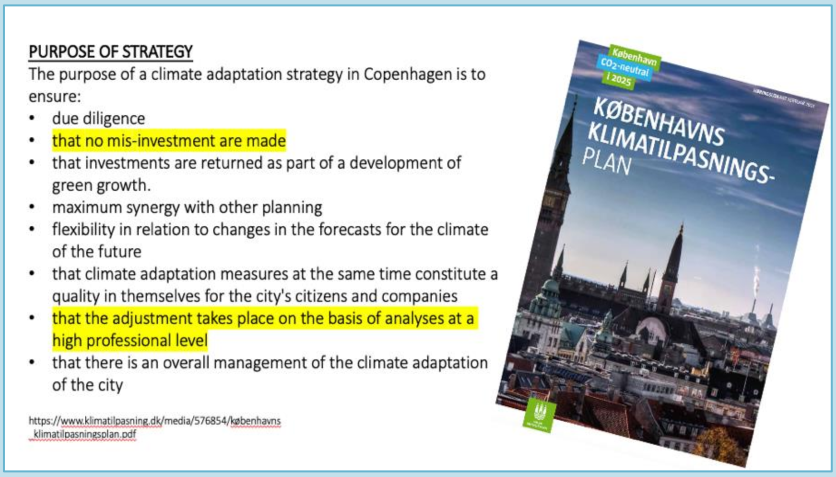


Table 3-1 focus on the main climate hazards perceived to constitute the main risks and which will also require the most adaptation investments into adequate measures.

URBAN CLIMATE HAZARDS IMPACTS AND COSTS OF ADAPTATION

CLIMATE HAZARDS	COSTS OF NO ACTION	ADAPTATION MEASURES	ADAPTATION COSTS	SOURCE
HEAT	23 thousand attributable deaths at 2°C of warming (mid century) in Europe, with estimated economic costs of €41 B/Y (COACCH)	Building design, Increased albedo, Green infrastructure: **green roofs, trees, green walls**, Parks, Fountains Ponds, Heat forecast warning	€7 B/Y	CWare estimate
HEAVY PRECIPITATION		Rainwater storage, SUDS, upgrading sewer systems, better land use planning	€4 B/Y	CWare estimate
FLOODING	Coastal flooding: €115-210B/Y River floods: €33B/Y	Dikes, beach nourishment, flood gates, anti-flooding valves and airbrick covers, raising houses	€14-16 B/Y	*COACCH project*
DROUGHT	Public water supply: €5B/Y Buildings&infrastruc: €2-3B/y	Waste water reuse, awareness-raising campaigns, extraction and desalination	NA	*Peseta IV, year 2100, 1.5oC*
WILDFIRES	NA	Awareness-raising, fire-break areas, more agroforested areas	NA	
LANDSLIDES	NA	Erosion protection, levees, emergency response training	NA	
STORMS	NA	Embedding wind-proofing in the design and planning urban development, early-warning systems and forecasting	NA	

Table 3-1 Urban adaptation measures and adaptation costs

Despite the huge uncertainties with the numbers listed in the above table, it is clear that cost-benefit ratio of investing in climate adaptation measures as opposed to 'do-nothing' is at least a factor 10. This is in actual accordance with WMO (2019)[iii], stating that Cost-benefit ratio of investing in climate adaptation is 1:10 within agriculture.

In the following subsections each of the climate hazards will be further discussed and detailed.

3.7.3 Heat

Case study – lowering urban temperature

Investments required to minimise UHI effect, e.g. lowering urban temperature is associated with investment into building design, increasing albedo effect, upgrade green and blue infrastructure, e.g. instalment of green roofs, green walls, planting trees, allocate more space for parks, fountains, ponds, etc. and early warning systems including social service preparedness.

Many cities are considering green infrastructure as a cost-effective approach to lower urban temperatures for future heatwaves, e.g. Copenhagen's 100K Trees strategy[iv], Hamburg's Green Roof strategy[v], Paris' Greening Programme[vi], Milan's Green Plan[vii], etc.

In our calculations below, we have focused on the costs of urban greening, meaning just one out of several measures likely to be needed as investment measures to minimise UHI effects. Planting trees in cities can be rather expensive if to be planted in sealed surfaces. Green walls are also relatively expensive to install and maintain. For simplicity, we use the costs of green roof instalment per m2 as proxy for the costs of urban greening and we assume a flat cost of 100EUR per m2, which is in the conservative end.

Climate adaption costs – UHI effect
Investment required to minimise UHI effect, e.g. lowering urban temperature
Calculations based on costs of establishing green infrastructure per m2 in EU cities

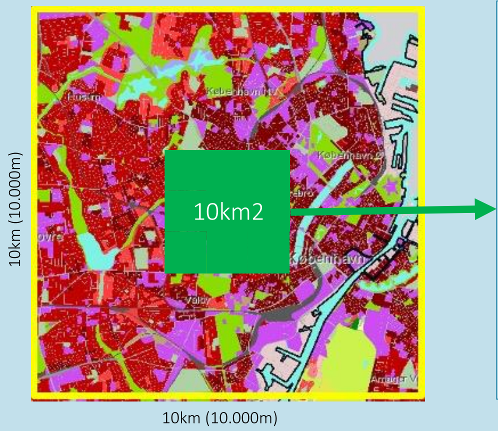
Measures:
- Building design
- Increased albedo
- Green infrastructure: green roofs, Trees, Green walls, Parks
- Blue infrastructure, incl Fountains Ponds, spraying
- Heat forecast warning

Costs:
- Costs of green infrastructure varies according to type and local conditions
- Tree planting in sealed areas, costs between 1.000EUR-20.000EUR per tree
- Green roofs costs: 1000EUR/m2
- Green walls costs: 2000-3000 EUR/m2
- Some cities have a goal of having 5m2 of green infrastructure per urban citizen
- Or upgrading xm2 building with green roof
- Or increase green coverage with 10%

Relevant CURE core services:
All heat APPs: APP01/02/03/08/09
APP10 Green roofs

Gaps:
NBS impact modelling tools

Potential added value of CURE services:
Better information, data, modelling leads to higher quality of investment decisions, and improved synergy with other planning purposes
Some cities will already have access to high quality of mapping and modelling tools, but many cities will not



Average EU large city: 1 mio inhabitant
10km*10km = 100km2
Green areas covers typically between 5%-25% of surface
10% additional green coverage equals 10km2 (=10 mio m2) can reduce ambient temperature by several degrees Celcius [Carvalho (2017), ADAPT-UHI]
Assuming 1m2 of greening costs 100EUR (ex Green roof)
Total costs per average city: 1BEUR over 15 years
For 100 EU cities: 100 BEUR over 15 years or nearly 7BEUR/Y

Figure 3-5 Case HEAT - costs of greening to lower UHI effect

For simplicity, we assume that each EU average city (1 million habitant, 10km*10km), will want to install an additional 10% additional coverage. This amounts to a cost of 1BEUR over a period of 15 years. Assuming we have 100 EU cities, this results in a total investment of 100BEUR over 15 years, or 7BEUR per year.

The value of CURE services

The CURE services, e.g. all the heat related APPs and in particular if further modelling features will be provided in the future, will provide optimal information, data, and modelling options leading to higher quality of investment decisions, and improved synergy with other planning purposes. Thereby the risk of mal-investment will be reduced.

Some cities will already have access to high quality mapping and modelling tools, but many cities will not or do not have the experience in using it.

3.7.4 Flooding and heavy precipitation

Case study – Heavy precipitation & Cloud burst: Climate adaptation costs

The type of investments needed to minimise risk of heavy precipitation and cloud burst includes measures like underground drainage tunnels and water reservoirs, re-design of squares and parks to make room for the water, green roads with construction rainwater beds and roadbeds, and de-coupling of rainwater and sewage water collection. Based on the case for Copenhagen, where such measures already have been projected and tendered by HOFOR[8], an amount of 2 BEUR from 2020 to 2035 (15 years) will be invested.

For the extrapolation process, we are assuming that across Europe another 50 cities (mainly in Northwest and central Europe) will have to invest in similar measures as for Copenhagen to build resilience against heavy rainfall and cloud burst. We are assuming that price level of

[8] https://www.hofor.dk/baeredygtige-byer/vi-skaber-baeredygtige-byer/klimatilpasning/

Copenhagen is +40% compared to EU average. As a result, we estimate that over a 15 years period, in the order of 60BEUR will be invested across 50 cities in Europe.

Climate adaption costs – Heavy rainfall/cloud burst
Investment required to minimise damages from flooding and heavy rainfall
CalculationSbased on Copenhagen case

Measures:
- Underground drainage tunnels
- Underground water reservoirs
- Re-organisation of squares and parks to make room for flood
- Green roads (construction of rainwater beds, and road beds)
- De-coupling of rainwater and sewage water collection

Costs:
2 BEURO from 2020-2035 for Copenhagen (over 15 years)
Extrapolation to 100 EU cities:
Across 100 European cities
Assuming half of the cities will have to invest in similar measures as Copenhagen
Assuming price level of Copenhagen is +40% compared to EU average
(50*2)*0,6 = **60 BEUR or 4BEUR/Y**
Reduction in malinvestments of just 2% equals savings of 1,2BEURO over a 15 years period

Relevant CURE core services:
APP05 Flooding
APP10 Green roofs

Gaps:
Green infrastructure and water absorptions potential, modelling tools

Potential added value of CURE services:
Better information, data, modelling leads to higher quality of investment decisions, and improved synergy with other planning purposes.
Some cities will already have access to high quality of mapping and modelling tools, but many cities will not

Figure 3-6 Case Heavy rainfall & Cloud burst

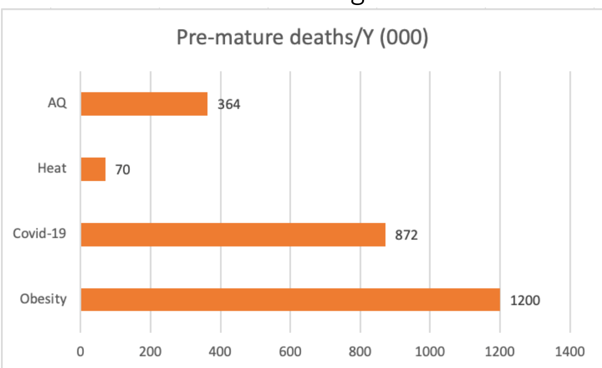
Potential added value of CURE service

Building on APP05 Flooding and APP10 Green roofs, further modelling tools related to green infrastructure, water flows and water absorption potential could guide decision making into finding the optimal set of solutions in a holistic perspective.

3.7.5 Human health – heat and poor air quality

Human health will in particular be affected by increased heat impact resulting in excess mortality and thermal discomfort due to increased temperatures.

Poor air quality is not a new human health threat and not as such to be regarded as a climate hazard, although climate change is likely to have a negative impact on air quality in the future, in particular due the impact of increased temperature on ground ozone (O3).



Although the air quality in general has improved over the last decades, due to a number of measures, we still had an estimated number of 364.000 premature death in 2019, the majority due to fine particulate matter. In comparison, pre-mature death due to heat waves is in average under 10.000 thousand a year, with the exception of extreme hot summers (e.g. 2003 with 70.000 pre-mature heat related deaths and mainly among the elderly population)[viii].

Just to put things in perspective, on a yearly basis we have 364 thousand people dying pre-maturely due to poor air quality in Europe, 70 thousand due to extreme heat wave (2003), 872 thousand due to Covid19 over a period of 16 months (March 2020 – July 2021) and more than 1.2 millions due to obesity yearly.

Impact pathways of heat

Therefore, using premature deaths as the main indicator for health impact related to heat is evidently only partly representative, other impacts such as increased hospitalization, discomfort, loss of productivity, impact on health services all represents huge societal costs.

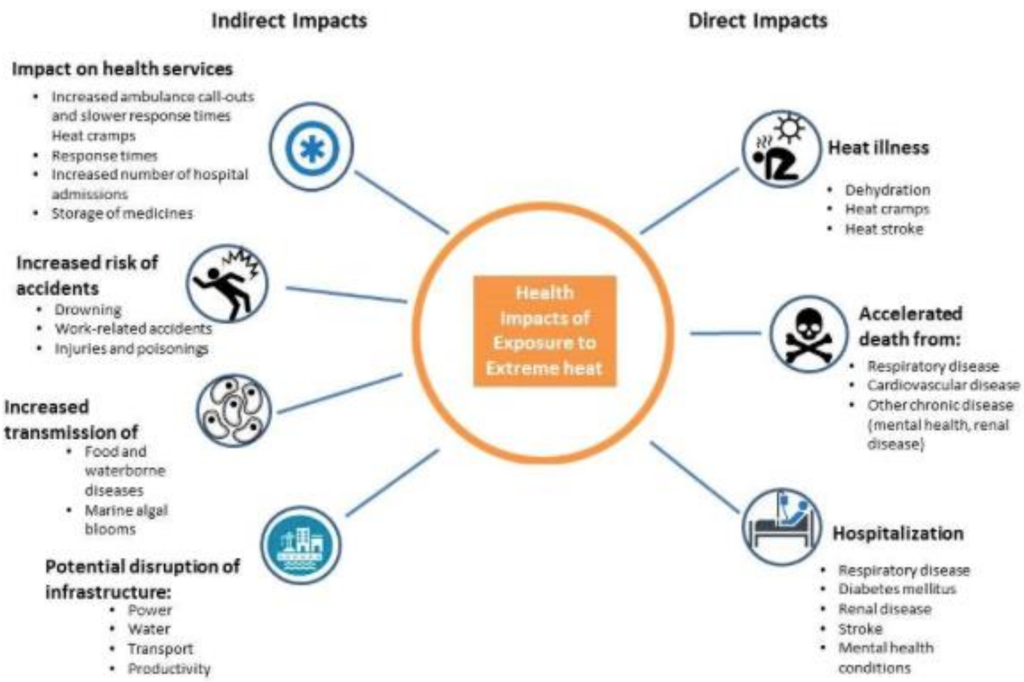


Figure 3-7 Impact pathways of poor air quality[ix]

3.8 Results of economic feasibility assessment

The results of the economic feasibility based on the assumptions made in section 3.2 are presented below in Figure 3-8 below.

It should be noted that these results are based with many uncertainties and consequently should be regarded as an 'order of magnitude' assessment only.

The three types of climate adaptation investments we have included in this economic assessment, namely measures related to heat, heavy rainfall and flooding are represented by the three orange columns. The two green columns represent the potential value of CURE services expressed as the value of reduces risk of malinvestments. While the blue column represents the costs of running the CURE system and services. All numbers are given MEUR and over 15 years.

- We are assuming that malinvestments will account for 10%.
- We are assuming that CURE services can reduce the risk of malinvestments by 10% (Scenario 10%) and 20% (Scenario 20%)

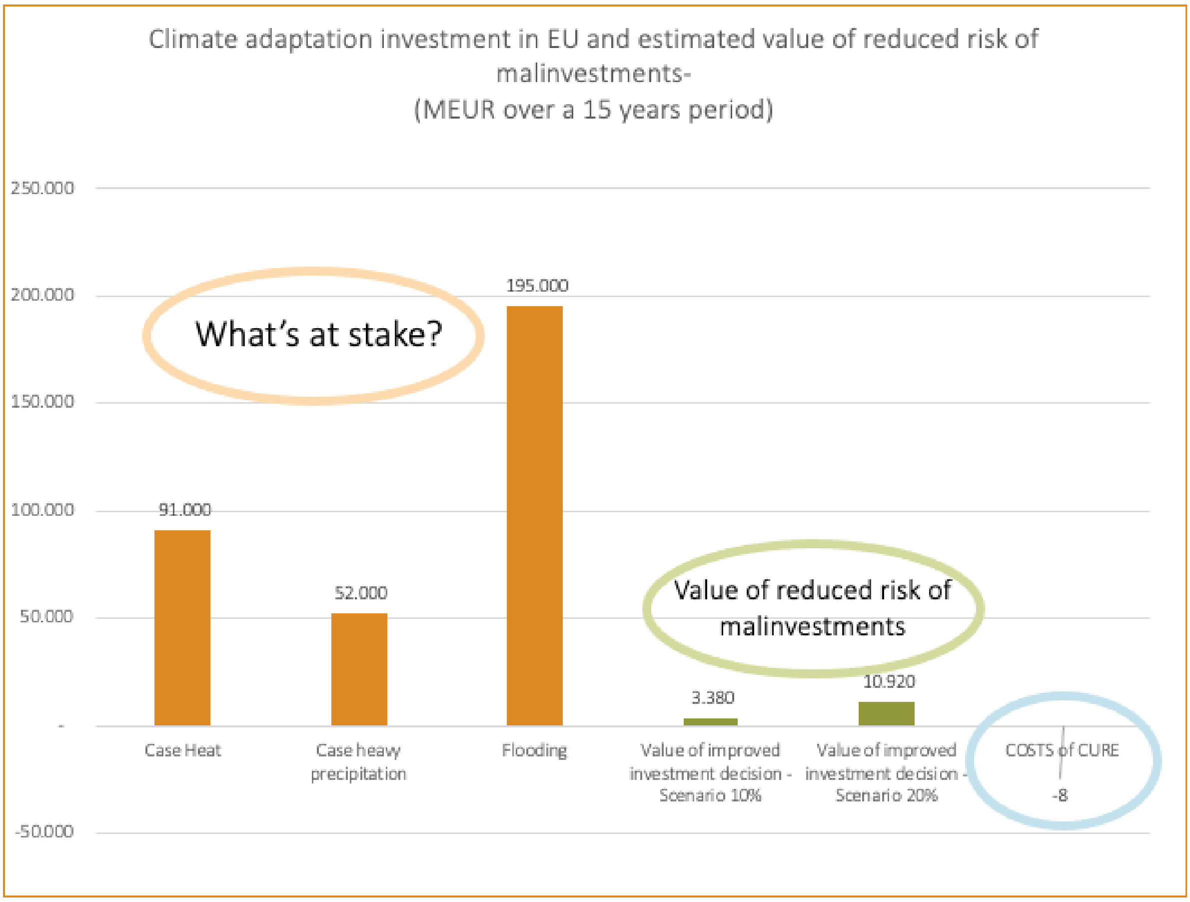


Figure 3-8 CURE economic feasibility

In this perspective, regarding the huge amount of climate investments required, the 'what's at stake' are enormous, in addition to this and a condition that might add to the risk of malinvestment, is that the type of measures to be implemented are not trivial, and when first projected are difficult to change.

On this background, any information, modelling, forecasting, visualisation that can add value to the decision-making process and minimise malinvestment would be beneficial. According to our assessment, the cost-benefit ratio of CURE are extremely positive 1:415 for the most conservative scenario (Scenario 10%).

4 CONCLUSIONS

Given the enormous challenges cities are facing now and over the next decades to invest in adequate measures to protect cities against a changing climate, the need to provide cities and decisionmakers with the best possible data and models to make the most cost-effective decisions and to avoid mis-investments are evident.

The economic feasibility as presented in Chapter 3 of this report provides an overview of the costs of operating the CURE system and the cross-cutting applications.

In assessing the value of CURE, we have applied a bottom-up approach and are assessing 'what's at stake' in terms of urban climate adaptation investment required over the coming 15 years. Data available on urban climate adaptation investment requirements are scarce or very high-level. The climate hazards facing cities are heat (UHI effect), heavy precipitation, flooding and drought. The assessment shows that in the order of 7BEUR is likely to be invested in greening cities on a yearly basis across European cities over the next 15 years. Likewise, in the order of 4BEUR will be required to invest in measures to build resilience against heavy precipitation and cloud bursts. While measures to adapt to higher risk of river and coastal flooding will amount to 15BEUR on a yearly basis over the next 15 years.

Non-optimal investments are likely to happen, we assume that 10% of the investment for one reason or another are malinvestments. We also assume that improved data and modelling tools can prevent malinvestments. On this background CURE will deliver a cost to benefit ratio of more than 1:400. It should be noted that there are huge uncertainties related to these calculations and should be regarded as 'order of magnitude' assessment.

These findings will be used as input for the exploitation assessment of CURE.

5 ANNEX CURE APP COST OVERVIEW

	Updated	Updated march22	Updated	Prototype only			Updated March22	Updated March23			Updated
Information from questionnaires for WP6.1	**APP01**	**APP02**	**APP03**	**APP04**	**APP05**	**APP06**	**APP07**	**APP08**	**APP09**	**APP10**	**APP11**
Lead	Forth, Zina	DLR, Mattia	Ubasel, Christian F	Ubasel, Christian F	GISAT, Toumas	GISAT, Toumas	VITO, Dirk/Hans	VITO, Hans/Dirk	Forth, Zina	Tecnalia, Efden	CWare, Louise
CAPEX (EUR)											
One-off investments per City	10.000-15.00(	€ -	€ 20.000	na	10.000-20.000	10.000-30.000	10.000-20.000	10.000	10000-15000	15.000-30.000	€ 8.000
100 cities in Europe, total	100000-1500(	<1€ (+1day labour cost of an operator if needed to organize the data)	Similar to APP1 and APP09						100000-150000		
		600EUR per City						€ 200.000		€ 425.100	€ 250.000
										€ 3.295.100	
Frequency of update?	Daily basis	Weekly, dependent on APP1						5-10 years	5 years	every 5 years	3-5 years
										Cheap option is LiDAR data, expensive option is VHR	
OPEX (EUR-year) by running 100cities			2.000-5.000	na	small	small					
Labour costs	20000	Depends whether the APP01 products are systematically organized in a database. If so, there is no basically no cost; if not, 1 day of work for an operator should be more than sufficient.							20000	€ 293.500	
Processing costs	50000	For 100 cities 2CPU/h (~0.05€) should be a reasonable estimate (the software takes around 1 minute per city on a standard pc)							50000	130.000 (LiDAR 3.000.000 (VHR	
Data Storage costs		100Mb (1Mb per city should be a reasonable upper bound) – 0.003€ per month									
Data aquisition costs											
Economics of scale	Yes factor 10	No	Yes	No	Yes	Yes	Yes	Yes	No		
Same set-up costs for a new city	yes	€ -						Yes	yes		
Upscaling											
Europe	Easy	Easy	Depends on input data	Flux tower needed	Yes if third party data is available	Yes	Yes for EU capitals)	Yes	Yes	Depends on input data available	Easy
Service provision											
User-interactive	yes		No	No	Yes	No	No	No	Yes	Yes	No
Output only	Yes	Yes, this is possible (the user specifies the area and period of interest).	Yes	Yes			Yes	Yes	Yes		Yes
Competing products					Yes						Yes, WHO
		None						none			
Depency											
Land cover, e.g. Urban Atlas	**APP01**	Local scale surface temperature dynamics					Output products		**Value for cities-top 2 political concerns**		
Soil permeability, e.g. Urban Atlas	**APP02**	Surface Urban Heat Island Intensity					Map		Climate change adaptation		
APP1, plus high res LULC, met data, etc	**APP03**	Urban heat emession monitoring					Table		Healthy Cities		
APP3, plus Flux tower	**APP04**	Urban CO2 emissions									
Terrain model, river network, Urban Atla	**APP05**	Urban Flood Risks									
EGMS, Urban Atlas	**APP06**	Land Subsidence									
Urban Atlas (building height)	**APP07**	Air Quality									
	APP08	Thermal Comfort									
	APP09	Urban heat storage Monitoring App									
	APP10	NBS									
APP07, population data	**APP11**	Health costs (EVA model)									

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