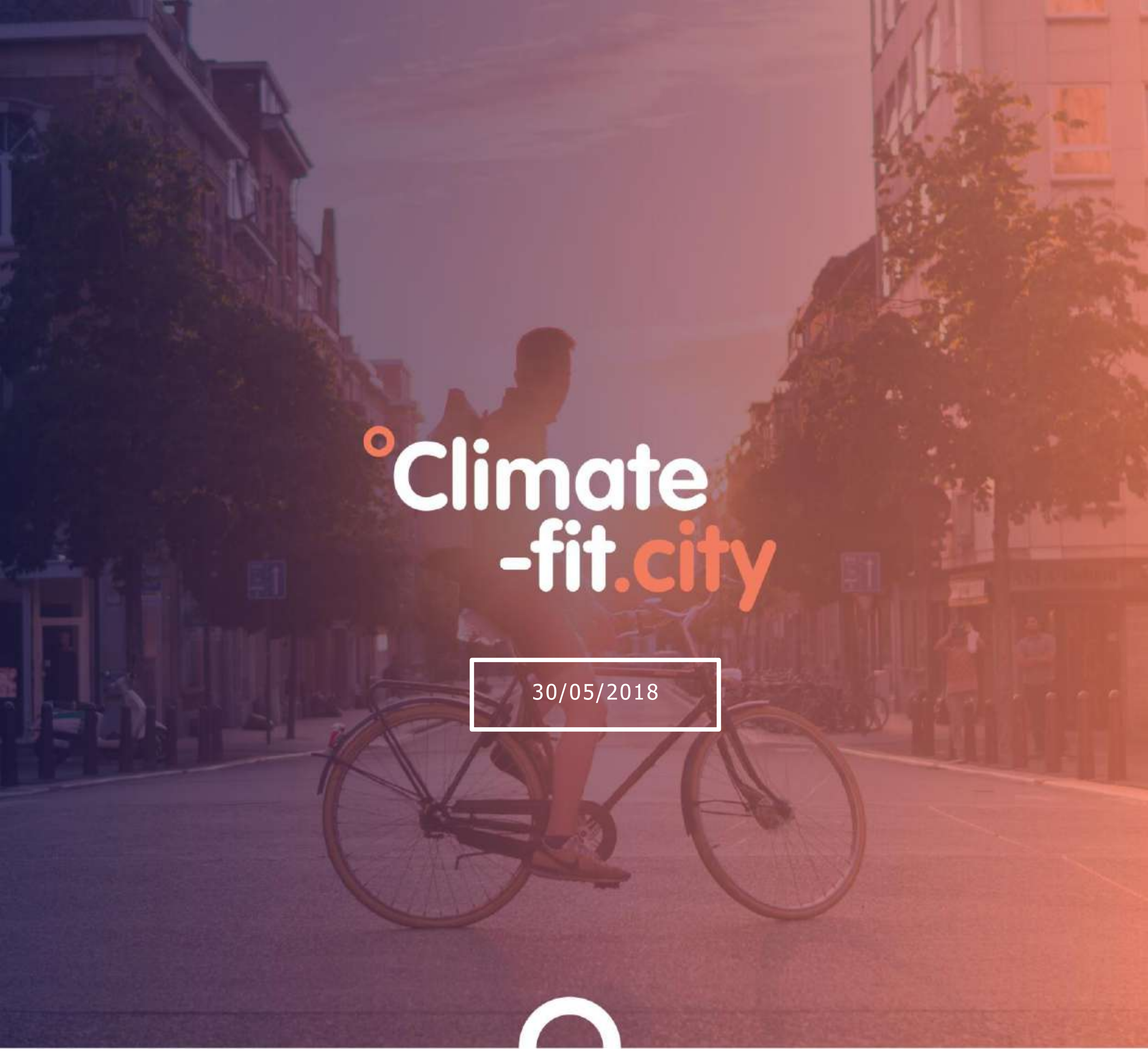

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30/05/2018

# Socio-economic impact assessment methodological framework

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**Dissemination level of the document**

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| X | PU | Public |
| | PP | Restricted to other programme participants (including the Commission Services) |
| | RE | Restricted to a group specified by the consortium (including the European Commission Services) |
| | CO | Confidential, only for members of the consortium (including the European Commission Services) |

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## Glossary

CBA (Cost-Benefit Analysis)
CEA (Cost-Effectiveness Analysis)
CGE (Computable General Equilibrium)
CVI (Composite Vulnerability Index)
GDP (Gross Domestic Product)
GEIAM (Global Economic Integrated Assessment Model)
GHG (Greenhouse Gas)
LST (Land Surface Temperature)
MCA (Multi-Criteria Analysis)
NZDep (New Zealand Deprivation Index)
PCA (Principal Component Analysis)
RoI (Return of Investments)
SBIA (Scenario-Based Impact Assessment)
SSBAR (Soprintendenza Speciale Archeologia, Belle Arti e Paesaggio di Roma)
UHI (Urban Heat Island)
VLS (Value of Statistical Life)
WP (Work Package)
WTP (Willingness to Pay)

## 1. Introduction

This document describes the socio-economic impact assessment methodology developed for assessing the services developed by Climate-fit.city project[1]. While all the services will be assessed using a common framework based on the value-chain approach, a specific set of indicators and data gathering and data analysis methods has been selected for each of the demonstration cases. This was necessary due to the different areas of action of the demonstration cases, the sectors they focus on and the specific characteristics of each service. The methodology is rooted on a vast literature review on the main impacts of climate change in the sectors addressed by the Climate-fit.city services and on the methodologies most often used for assessing them. This deliverable is the first output of Task 6.1 Socio-economic impact assessment methodology development.

The document is structured as follows: Chapter 2 introduces the issues raised by climate change in urban areas. Chapter 3 provides an overview of the main literature about climate change impacts in relation to each of the demonstration cases. Chapter 4 introduces and describes the main methodologies to be utilized for conducting the socioeconomic impact assessment. Chapter 5 detects the most significant areas of impacts of the provided climate services and describes related methods and data gathering activities for socioeconomic impact assessment. Chapter 5 addresses conclusions for the report and its significance for future activities of the Climate-fit.city project.

The Description of Action, reports that this deliverable would have also included an annex with summary of the stakeholder events and a report on the internal project workshop. However, the stakeholder's workshops are already described in full details in other deliverables (D2.1 and D2.2), while the partners workshop results are incorporated in the methodology here described and opportunely mentioned. Moreover, as this deliverable is a public report, it was decided to put the description of the internal workshop (structure, participants, etc.) in the periodic report 1 (covering months 1-12) only.

## 2. Climate change in urban areas

Since the last decade, researchers, policy-makers, and practitioners have acknowledged that climate change represents one of the factors triggering more frequent, intense, and durable hazards worldwide under the form of weather and climate extreme events (McCarthy, 2001; Field et al., 2012; 2014). In this way, climate change can contribute both to modify the hazards profile of a specific area, region, or country, and to exacerbate social, economic, and environmental vulnerability factors (O'Brien et al., 2006). In turn, this contributes to increased risks associated with extreme events. Some regions have already experienced costly impacts of weather and climate extreme events in terms of casualties and human health, as well as in terms of economic loss and damage to e.g. public and private properties, infrastructure and assets, crop production and livestock, tourism, and food security (Leal Filho et al., 2018). In a climate change regime, these impacts can be worsened for example by further damaged infrastructures and economic loss, environmental degradation, as well as by impact on human health leading to casualties, hospitalization, and/or aggravation of pre-existing pathologies (Watts et al., 2015; 2017). Therefore, services such as the ones developed in the Climate-fit.city project, able to offer information on climate change related phenomena, can be crucial

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[1] This document is developed as part of the PUCS (Pan-European Climate Service) project, which has received funding from the European Union's Horizon 2020 Research and Innovation programme, under the Grant Agreement number 730004. For marketing purposes, the project name is changed to 'Climate-fit.city' for internal usage and communication to end-users and stakeholders.

in understanding actual and potential impacts on environment, economy, and society and to inform a set of effective mitigation and adaptation strategies to be implemented at multiple scales and levels.

Worldwide, urban areas are the human agglomerations where the potential and actual impacts by climate change can be the severest. Indeed, given their high concentration of population and crucial functions and infrastructure, urban areas are highly exposed and sensitive to climate change (Satterthwaite, 2007). Several urban areas and metropolitan regions are also located on the coasts, in drought-prone areas or in low-lying plains, and are consequently exposed to potentially occurring single, multiple, or cascade climate change-related hazards (De Sherbinin et al., 2007). Furthermore, climate change has direct implications for urban functions and services through changes in temperature and precipitation patterns (Carter, 2011). For example, climate change potentially enhances the likelihood of flooding and of storm surge/wave damage and shoreline erosion in coastal regions, while changes in rainfall patterns can lead to increased tropical storms, flooding or water shortages (Solecki et al., 2011). Therefore, climate change has complex and uncertain direct and indirect impacts for urban areas to contend with. A better understanding of current and future impact trends on urban functions is required (Carter, 2011). In this way, urban governments and institutions are called for their direct involvement into climate change response by developing and implementing their own strategies (Bulkeley, 2010).

The Climate-fit.city project focuses on six areas of urban context which can be affected by climate change, i.e. Public Health, Building Energy, Urban Planning, Emergency Planning, Active Mobility, and Cultural Heritage. A desk-based literature review has been conducted to provide an overview of the state of the art related to the impacts by climate change on the selected areas of urban context (Webster and Watson, 2002). The literature review will constitute the background to inform a specific methodology for the assessment of socioeconomic impacts by Climate-fit.city services compared to the situation without those innovative services. The literature review will summarize the existing literature and will synthesize it in a way that will facilitate the mapping and assessment of socioeconomic impacts along the project. The next chapter – dedicated to such a literature review - is articulated in five paragraphs, one for each of the demonstration cases. Each paragraph is related to one demonstration case, however Building Energy and Urban Planning will be discussed in the same paragraph as they present a number of overlapping themes in relation to climate change and its impacts.

# 3. Literature review

## 3.1. Demonstration Case: Climate and Health

The demonstration case of Climate and Health will be developed in Barcelona. Temperature-mortality models are expected to be used to develop the urban health service, which will consist in the generation of assessment reports of heat-related mortality risks in different parts of the city and on different social groups. These reports will incorporate the climate data from the urban climate model for the different identified driving global/regional models, scenarios of greenhouse gas emissions and/or time horizons. Projections will also be used to identify the most vulnerable areas of Barcelona according to the expected changes in the climate variables, and the current sensitivity of individuals to temperatures in the different

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administrative units. This demonstration case has the final objective of assessing and predicting temperature-related mortality and developing related adaptation measures.

Extreme heat is a weather and climate event that challenges public health systems worldwide. Under acknowledged anthropogenic climate change scenarios, prolonged and more frequent days of extreme heat can occur. These prolonged heat days are usually defined under the broad definition of heat-waves. There is no standard definition of heat-waves, as the World Meteorological Organization has not provided yet a globally recognized definition (Koppe et al., 2004). However, for the scope of the project the basic definition of a heat-wave by Robinson (2001) will be adopted. Accordingly, a heat-wave is considered as "an extended period of unusually high atmosphere-related heat stress, which causes temporary modifications in lifestyle and which may have adverse health consequences for the affected population" (Robinson, 2001, p. 763).

Urban areas tend to be hotter than rural areas, especially at night. In urban areas, heat creates the commonly recognized phenomenon of an Urban Heat Island (UHI), whose effects are exacerbated during a heat-wave (Oke, 1982; Arnfield, 2003; Buscail et al., 2012). The UHI phenomenon is produced by several factors, including the increased absorption and reflection of the sun on concrete compared to green or brown spaces; reduced cooling from breezes due to airflow obstruction from buildings; and anthropogenic heat release from anthropogenic activities. According to Helbich et al. (2014), UHI is a product of the city morphology and topography, through the formation of urban canyons, such as areas between building facades during day-time. Under heat conditions, urban canyons may heat more quickly than surrounding lower density or natural areas due to multiple reflections of solar radiation and the absorption of heat in building surfaces, although these processes may be counteracted when urban canyons receive considerably less direct solar radiation due to building shadows. On the other side, natural areas reflect more of the radiation back into the sky and additionally cool due to evapotranspiration (e.g., vegetation's transpiration and water evaporation). During night-time, urban canyons cool much less than natural areas, due to both limited sky view and solar energy storage in building surfaces (Helbich et al., 2014). There is therefore an excessive heat in urban canyon areas which can lead to prolonged days of heat, generating heat-waves and posing problems for human health, building energy efficiency, and the whole urban functions (e.g., hospitals, built environment, water availability, early warning systems, and so on). UHI can also worsen air quality by increasing the formation of secondary pollutants such as ozone (Buscail et al., 2012).

### 3.1.1. Morbidity and mortality

The association between heat-waves and health illnesses such as hyperthermia and hypothermia, heat syncope, heat exhaustion, stroke, and dehydration, is very well recognized in the literature. Association has also been found between heat-wave and hospital admissions for respiratory diseases, cardiovascular diseases, heat-related causes, diabetes and circulatory diseases (Watts et al., 2015; 2017). Subjective elements such as perceived thermal discomfort can be combined with existing illnesses, posing serious health risks to the population, especially to vulnerable groups such as the elderly and young children (Leal Filho et al., 2018). Therefore, heat-waves are associated with increase in both mortality and morbidity (Bittner et al., 2013; Vardoulakis et al., 2015; Martinez et al., 2016).

Deaths associated with heat-waves occur when the human body is exposed to rapidly rising environmental temperatures which challenge the capacity of the human body to cool itself by increasing blood circulation and perspiration (Amengual et al., 2014). For increasing mortality and morbidity, the most hazardous conditions related to heat-waves emerge when extreme daytime temperatures are combined with warm night-time temperatures, high humidity, and light winds for several consecutive days. Indeed, in these climatic conditions capacities of the human body to reduce the evaporation of perspiration from the skin are further reduced (Amengual et al., 2014; Habeeb et al., 2015).

Episodes recorded worldwide have highlighted the consequences of heat-waves on health, as well as on society and economy. In 2003, heat-waves of unprecedented intensity and duration in the European Union resulted in over 70,000 estimated fatalities. In Italy, between June-August 2003, just in the 21 Italian regional capitals, at least 3000 excess deaths were recorded in comparison with the same period in 2002 (Conti et al., 2005). In Australia, it is estimated that the early 2009 heat-wave resulted in at least 500 heat-related deaths (Akompab et al., 2013a; 2013b). In the US, the Midwest heat-waves of 1995 and 1999 led to more than 1,000 and 300 casualties, respectively (Habeeb et al., 2015). In the period 1999-2009, the United States Center for Disease Control reported 659 cases per year on average of heat-related deaths in the US (Boeckmann and Rohn, 2014). In 2010, heat-waves in Russia caused over 20,000 victims (Habeeb et al., 2015). Similarly, Zacharias et al. (2015) found that daily excess mortality will exist in the future for heat wave-related mortality due to ischemic heart diseases in Germany.

To estimate the number of deaths attributable to heat for 15 major European cities, Baccini et al. (2011) utilized a Monte Carlo approach and defined four alternative scenarios for each city by selecting specific daily series of baseline mortality and exposure. These scenarios were used for assessing heat impacts during summers hypothetically cooler and warmer than the overall (up to) 11-year mean. According to the findings, the number of deaths which are attributable to heat per summer ranged from 0 in Dublin to 423 in Paris. Highest impacts were recorded in three Mediterranean cities (Barcelona, Valencia, and Rome) and in two continental cities (Budapest and Paris). The largest impacts were on people over 75 years, but in some cities heat-related deaths were also found for younger adults. These heat-related deaths significantly increased under warming scenarios. Anderson and Bell (2011) estimated the mortality effects of heat-waves across US in 43 communities in the period 1987-2005. The study utilized a generalized local linear model controlling for daily maximum temperature and for days of the week. Heat-waves mortality effects were found being influenced by the heat-wave's intensity, duration and timing in the season. Probably, this effect modification resulted from physiological responses to heat and/or behaviour modifications. The study therefore confirmed that heat waves' intensity, duration and seasonality influence heat-wave mortality, and that heat-waves will be longer and more intense and frequent in the future.

### 3.1.2. Socio-economic conditions

Urban populations are particularly vulnerable to excessive heat and heat-waves, as in urban areas there is often a concentration of lower-income individuals lacking basic access to resources (e.g. adequate housing, sufficient air conditioning, or healthcare facilities with adequate medical assistance) (Habeeb et al., 2015). Epidemiological studies demonstrated that certain groups of urban population are more vulnerable to heat-waves because of diverse underlying physiological and contextual factors (Akompab et al., 2013a; 2013b). The elderly, young children, chronically ill people or individuals being exposed to socio-economic or environmental risk factors are usually more vulnerable (Zacharias et al., 2014). Also, people taking medications that impair thermoregulation, very young children, socially isolated elderly, and people physically active outdoors during very hot periods are those identified as particularly at risk (Boeckmann and Rohn, 2014).

Differences in heat-wave vulnerability are also acknowledged and can be attributed to social and economic disparities which are strictly linked with ethnicity, socio-economic status, and poor health outcomes. Some studies found that ethnic groups, particularly those living in poorer social, environmental, and economic conditions, are subjected to specific heat-wave related health issues (Basu et al., 2012). Hansen et al. (2013) reported that 'Non-White' minority groups in North America usually have higher morbidity and mortality rates associated with heat-waves. African Americans are particularly vulnerable to heat-waves in the US, insofar the mortality rate during heat-waves in Los Angeles was almost the double of the city's average. During the 1995 heat-wave in Chicago, African Americans were disproportionally represented in the heat statistics and were 1.5 times more likely to die than Whites. Notwithstanding this, it is worthwhile mentioning that the association between socioeconomic factors and heat vulnerability, however, can vary between and within countries (Zhang et al., 2013).

Among other socio-demographic factors, extremes of age classes (children younger than five and the elderly) are associated with an increased health risk, as well as social isolation, low income, or citizenship status (immigration). Tran et al. (2013) investigated heat vulnerability in slums in Ahmedabad (India), and found that heat exposure occurred at home, at work, and in transit, to individuals mostly homemakers or unemployed. Furthermore, pre-existing conditions and limited access to resources influenced susceptibility to heat. Education level can also contribute to modify the heat-mortality profile; for example, individuals with at most a high school education have higher death rates during heat-waves than people with higher education (Buscail et al., 2012). Madrigano et al. (2013) found that the effects of heat-waves on both acute myocardial infarction occurrence and mortality in the Worcester metropolitan area (US) were greater among the population living in census blocks with a higher proportion of poverty. Both individual and neighbourhood characteristics related to lower socioeconomic position were indeed found to enhance the relationship between temperature and mortality. One of the reasons might be less availability of air conditioning or other adaptive measures, which may require money investment. According to Vandentorren et al. (2006), pre-existing medical conditions during heat-waves in Europe in 2003 were also important risk factors for death, including mental disorders, neurological disease, cardiovascular disease, cancer, obesity, and high blood pressure. Finally, the absence of social connectedness, e.g. no social, religious, cultural, or leisure activities, acts as a six-time multiplier of mortality risk. In their study on heat-wave-related deaths in Italian cities in summer 2003, Michelozzi et al. (2005) found that the highest number of excess deaths occurred in susceptible population subgroups which might reflect the higher proportion of elderly people of low socio-economic status who remained in cities during summer. In a study on effects of heat-waves in São Paulo (Brazil), Son et al. (2016) found that heat effects were higher for females than for males, and those ≥75 years had 7.1% higher risk than those 0-14 years.

### 3.1.3. Housing conditions

Vandentorren et al. (2006) investigated heat-wave risk factors for housing in Vienna. The principal heat-wave risk factors for buildings were the construction date (prior to 1975) and the comfort level (the percentage of dwelling units with private toilets). The principal risk factors related to the individual dwelling units were the lack of thermal insulation (assessed by building date and questions about insulation) and, as said earlier in this chapter, living on the top floor. Also, the higher the number of rooms, the less is the risk, while the number of windows per 50 $m^2$ increases risk. In terms of behavioural factors, behaviour such as visiting air-conditioned or cool places, dressing lightly, or using cooling techniques and devices directly reduced risk, whereas opening the windows during the afternoon (instead of opening them at any other time) was associated with an increased risk of death. However, Anderson and Bell (2009) noted that heat-waves have a lower mortality impact when communities have more central air conditioning, and this likely explains some of the regional variation in heat effects. Heat-wave effects, however, did not have a strong association with air conditioning. This is because it is likely that the protection afforded by air conditioning was sufficient to reduce effects by high temperature but not to prevent more extreme heat-wave effects.

## 3.2. Demonstration Cases: Building Energy and Urban Planning

Climate-fit.city will focus on two important components of the built environment, that are Building Energy and Urban Planning. These cases are here presented together as numerous overlaps and interactions exist among these two components, particularly in relation to heat-waves. The demonstration case of Building Energy will be developed for the city of Berne. Meteotest will enhance its Meteonorm software[2] and web service to account for urban climate conditions, in particular the UHI effect, using UrbClim (as into the WP 5) output fields. This entails generating time series of a so-called Typical Meteorological Year, as well as extreme (hot/cold) years, both for the current situation and under future climate conditions. 'Urbanized' Meteonorm data for Berne and Antwerp will be employed to simulate building cooling and heating loads, and thermal comfort levels, for three types of buildings (single family house, apartment building, office building), using two building standards (historic of 1970 and current of 2015) and the IDA-ICE building simulation tool. In this service, first a comparison of the 'urbanized' Meteonorm data with existing datasets is made before proposing them to users and stakeholders. This comparison will be the most important argument to use this kind of data.

The demonstration case of Urban Planning focuses on the (cor)relation between urban climate/heat and urban land use structure and development in Prague, Ostrava, and Hodonín (Czech Republic). Various urban planning scenarios will be introduced by modifying the city's land use plan and will be combined with different climate development scenarios. The urban planning scenarios will represent different city development strategies at different levels of spatial detail and decision-making processes. The effect of these urban planning scenarios on urban temperature conditions will be explored. An online analytical platform will be prepared to enable the user to visualize and interactively analyse this multi-temporal temperature information and to enable tailored scenario analysis based on climate change modelling and varying urban land use datasets.

Worldwide, urbanization trends grow and contribute to a radical increase of urban density, driving land use change and highly influencing the way people live in, use, and move into

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[2] See details of the software at the dedicated website: www.meteonorm.com (Accessed 04/05/2018)

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cities. Urbanization trends contribute to create - or worsen conditions of - agglomerations and neighbourhoods with problems of uncontrolled high density, congestion, and air pollution due to high or increasing levels of individual motorised transport, particularly cars (Gössling, 2013). The form and organization of the built environment, both in terms of buildings and urban planning, highly influence temperatures and the potential formation of heat-waves, particularly in hot summers. Meanwhile, UHI can have potentially significant medium- and long-term impacts on the energy use in public and private buildings, as well as on the urban built environment (Berger et al., 2014).

### 3.2.1. Urban form and heat-waves: compactness vs. sprawl

A long-standing academic and policy-making debate discusses challenges and opportunities of the two commonest urban forms, i.e. compact vs. sprawled, and their degree of sustainability (Gordon and Richardson, 1997; Dieleman and Wegener, 2004; Catalán et al., 2008). Such debate has been revived in the last years with the raising concerns around climate change and greenhouse gas emissions. On the one side, a dense and compact urban form reduces urban expansion, and this can be helpful in turn in reducing travel distances and increasing non-motorized transport and shared transportation modes in the city. In this way, a compact urban form allows decreasing energy consumption, which contributes to climate change mitigation. On the other side, the compact urban form influences the formation of urban canyoning and UHI, therefore higher densities may exacerbate UHI, in turn generating the need for more cooling and increasing energy use (Lemonsu et al., 2015).

Lemonsu et al. (2015) explored the relationships between different pathways of urban development (five contrasted urban expansion scenarios) and UHI trends in Paris. Accordingly, in all scenarios night-time UHI is limited to the most densely built-up areas (almost overlapping with the city centre) and reaches up to 2.5-3.0 °C. Conversely, in daytime the residential neighbourhoods represent the warmest places in the city, with temperature increasing by 1.0-1.5 °C. UHI amplitude is also higher at night than during the day, therefore city densification can potentially lead to increased heat-wave risk when compared to urban sprawl. While from these results it can be said that compactness contributes to the most uncomfortable thermal conditions for outdoor environments, however when considering separately days and nights or by not considering the population distribution, results are the opposite. This is because the compact city reinforces the UHI at night but also favours solar protection, hence contributing to cool down daily temperatures. Other studies reported that urban sprawl can contribute to UHI (Frumkin, 2002; Stone Jr., 2008). Stone et al. (2010) examined the correlation between a sprawl index (based on land-use data from 2000) and the rate of increase in UHI in metropolitan regions of the US over the period 1956-2005. The rate of increase in the annual number of heat-waves in the most sprawling metropolitan regions of the US was more than double the rate of increase observed in the most compact metropolitan regions. Similarly, Ewing and Rong (2008) found that urban sprawling counties in the US are less energy efficient than compact urban areas, as they are more likely to be occupied with single-family detached houses, usually bigger than houses in compact urban areas. This usually leads to higher residential energy use.

### 3.2.2. Landscape metrics (vegetation, green areas) and UHI

Land Surface Temperature (LST) or surface UHI could be related to the types of land cover and use. Tight relationships, for example, were found between spatial structure of thermal patterns and urban surface characteristics (Buyantuyev and Wu, 2010; Li et al., 2011; Connors et al., 2013; Maimaitiyiming et al., 2014). Among the others, Li et al. (2011) investigated the relation between landscape composition and configuration and UHI in the Shanghai metropolitan region (China). The study analysed LST in relation to vegetation index, vegetation fraction, and the percentage of impervious surface area, by using Landsat images and high spatial resolution land-cover/land-use maps. Significant variations in LST were found according to variations of landscape metrics, therefore such metrics can be considered as good predictors of LST on urban scale. A strong negative linear relationship was found between LST and vegetation index, together with a stronger negative linear relationship between LST and vegetation fraction. Among the residential land-uses, areas with low and middle-rise buildings and low vegetation cover have higher temperatures than areas with high-rise buildings or high vegetation cover. Similarly, Maimaitiyiming et al. (2014) investigated the relation between landscape metrics and UHI in Aksu (Northwestern China). The study combined green spaces maps derived from Landsat Thematic Mapper (LTM) imagery, and land surface temperatures data retrieved from LTM thermal band. The study found that while the percentage of landscape is the most important variable to explain land surface temperature dynamics, spatial configuration of green space also has significant effects on LST. Indeed, the combination of edge density and patch density was found as being the most deterministic factors of LST compared for example to the effects of each single variable.

Increasing urban green spaces by increasing vegetation (e.g., woodland, cropland, parks, reserves, and gardens, tree rows) is acknowledged as an effective way to mitigate the effects of the UHI. Urban greening generates evapotranspiration and reduces the heat storage process by impervious surfaces (Charlesworth, 2010). Indeed, green areas provide a range of invaluable health and environmental benefits, as they create possibilities for alternative transportation networks, such as cycling routes, which will have lower impacts on nature and the environment and increase the physical activity levels of citizens (Vandermeulen et al., 2011). Optimizing the configuration of green space is therefore a fundamental policy goal for cities coping with climate change and UHI effects, with notable implications for green space management in rapidly urbanizing regions (Charlesworth, 2010). However, as Maimaitiyiming et al. (2014) pointed out, it is also important stressing that the configuration of green spaces is the most deterministic metric that affects LST. It is also worthwhile pointing out that land and water availability and resources can represent major constraints for the implementation of greening strategies. Vegetation density and groundwater status, for example, highly depend on water and land resource availability, which are in turn both related to weather and climate conditions. In addition, if heat-waves are prolonged, the benefit of greening runs also at risk of being less effective even though vegetation is irrigated.

### 3.2.3. Building energy and heat waves

The building sector and the built environment of urban areas are among the largest energy-consuming sectors worldwide as they account for a significant part of the total energy consumption. In 2004, the building sector accounted for 40%, 39% and 37% of the total primary energy requirement in US, UK, and the European Union, respectively. In China, the total national energy use of the sector increased in the last 25 years from about 24% in 1996 to up to 35% in 2020. Worldwide, buildings account for about 40% of the total primary energy requirement and contribute to more than 30% of $CO_2$ emissions (Yang et al., 2014).

Therefore, the poor energy performance and large utilization of electric power and facilities by the building sector contributes to produce large amounts of GHG (Greenhouse Gas) emissions, in turn contributing to climate change. This raises concerns about global energy balance and highlights the necessity for improving the buildings' energy efficiency in terms of: design and construction of building envelopes (e.g. thermal insulation and reflective coatings, sensitivity and optimisation, and life-cycle analysis); technical and economic analysis of energy-efficient measures for buildings' renovation; and the performance of heating, ventilation, air conditioning, and lighting systems (Yang et al., 2014).

Indeed, UHI contributes to increase indoor temperature and modify the energy budget of buildings (Santamouris, 2014; Palme et al., 2017). Temperature increase reduces the need for heating in the winter but increases the cooling demand in the summer (Gago et al., 2013). Therefore, it generally results into an increase in cooling energy use and a decrease in heating energy use for buildings located in urban areas compared to those in rural areas (Hwang et al., 2017). The increase of the peak and total energy demand, particularly required for cooling purposes during heat-waves and hot summers, is also associated to an increase in the concentration of urban pollutants, as well as to worsen thermal comfort conditions in outdoor spaces (Santamouris, 2014). An increase in heat stress would increase the risk of summer overheating also in naturally ventilated buildings. For air-conditioned buildings, this would result in more space cooling requirement during hot summers. In mid-latitude areas where both heating and cooling requirements are significant, the magnitude of increase in cooling and reduction in heating could be comparable. In low latitude regions an increase in energy use for cooling would occur with warmer climates and imply more energy consumption with contribution in production of GHG emissions (Yang et al., 2014).

Hwang et al. (2017) investigated the spatial and temporal distribution of impacts by UHI and climate change on residential thermal comfort and cooling energy in Taiwan. Cooling energy data were obtained by utilizing the 5 $km^2$ hourly meteorological grid for three timespans generated from the downscaling model for dynamic building energy simulation. The meteorological grid was then categorized as 4 city grids, 13 town grids, and 40 countryside grids based on the morphology within each grid. Dynamic building energy simulations were then conducted against a typical residential apartment in Taiwan. The study found that the urban ambient temperature is amplified by the UHI effect and climate change, in turn leading to changes in the building energy demand and usage. Such demand particularly increases in cooling dominant regions such as hot-and-humid Taiwan, given that the increase in summer cooling demand is far larger than the decrease in winter heating demand. Specifically, the study found that:

- a living room located in a city or town exhibited high overheating risk in all three timespans, while rooms in a city or town would experience both daily and nocturnal high risk of overheating in the timespan 2075-2099;
- the fluctuation ranges of the intensity of UHI results in all the three considered timespans in high percentage increases of residential annual cooling energy ranging;
- the deterioration of climate due to urban warming would potentially lead towards an excessive cooling energy consumption and to an urban ambient temperature rise of 1°C.

Similarly, Berger et al. (2014) investigated the implications of climate change on heating for four buildings of different material and age in Vienna. Accordingly, values of heating demand under current and future heat conditions vary based on the different periods of construction and on the location. Therefore, differences were found in net cooling demand between hottest

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and coldest urban and semi-urban locations. Particularly, recently built office blocks have low net heating demands compared to the rest of the city and such demands will further decrease over the temporal range, but their net cooling demands tend to be even higher than heating requirements. The same study also found that solar and internal heat loads from electronic equipment make up for the most significant drivers of cooling demand in the sample buildings. Therefore, high glazing fractions of the exterior wall and high occupancy which favour solar and internal heat loads strongly influence a buildings' performance under hot summer conditions. In this way, in his study on Thessaloniki (Greece), Vartholomaios (2017) confirmed that two key energy efficient building design strategies exist, that are high compactness of building volumes and southern orientation. Compactness of building volume is important for energy effectiveness, as a compact arrangement of "passive zones" is a consistently effective strategy, especially when a southern orientation of building mass is not possible. Also, compact perimeter urban blocks are generally a more efficient urban form than pavilions and slabs. In case southern orientation is possible, two additional design strategies significantly enhance its potential, that are: to keep minimum distances in order to maximise winter solar gains, and to elongate urban blocks along the East-West axis.

### 3.2.4. Indoor temperature and work productivity

Indoor temperatures and related thermal comfort or discomfort represent important indoor environmental parameters which influence work productivity and performance (Huizenga et al., 2006; Wagner et al.,2007). Literature has indeed shown that the indoor thermal comfort by occupants vary with season, building type and shape, and other factors. To adapt to different expected temperatures, occupants modify their clothing levels. In addition, air velocities and air humidity values vary among buildings and affect thermal comfort. Expectation by peoples regarding temperature often vary according to previous experiences. For example, occupants of naturally ventilated buildings without air conditioning are more thermally satisfied over a broad range of temperatures than occupants of sealed air-conditioned buildings (De Dear et al., 1998). The level of thermal comfort has a profound impact on work performance (van Hoof et al., 2010), and can represents a useful predictor for work performance. According to the literature review by van Hoof et al. (2010), losses or gains of up to 15% of turnover in a typical office organization might be attributable to the design, management and use of the indoor environment. Studies also found that links exist between the improvements to the indoor environments and reduced medical care cost, reduced sick leave, better performance of work, and lower turnover of employees (see van Hoof et al., 2010, and references therein). Several studies[3] also demonstrated that performance is maximized when the air temperature is approximately 22°C, therefore when indoor air temperature rises above or falls below 22°C work performance decreases. However, uncertainty still exists about the actual temperature which maximizes productivity as well as about the actual magnitude of performance changes.

## 3.3. Demonstration Case: Active Mobility

The demonstration case of Active Mobility will be developed in Vienna, where the Urban Mobility Plan[4] is promoting the improvement of conditions for pedestrians and cyclists to contribute "*to an easing of the burden on public transport and infrastructures for car traffic*".

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[3] See literature cited in https://iaqscience.lbl.gov/si/performance-temp-office (Accessed 27/04/2018).

[4] https://www.wien.gv.at/stadtentwicklung/studien/pdf/b008443.pdf (Accessed 15/03/2018)

Therefore, knowledge about current and future climate attractiveness for walking and cycling in the city allows to (i) support cyclists and pedestrians in finding the climatically most comfortable routes, and (ii) to identify stretches of lanes and routes that are particularly exposed to extreme weather events (e.g., heat or wind) and hence show a need for special adaptation measures (e.g. shading, greening, water dispensers, etc.) in order to improve the climate resilience of active mobility. The Demonstration Case of Active Mobility is planned to provide climatic information to support improving the comfort of active mobility, with a particular focus on cycling. Setting up the planned climate service for active mobility requires the following steps: 1) Calculating response functions, by modelling the weather and climate sensitivity of urban cycling; 2) Determining the climate attractiveness, by applying the response functions on current and future climatic conditions, and 3) Integrating the information into the "Bike Citizens Analytics" tool.

### 3.3.1. Climate change and active mobility

In urban areas, the transportation sector has complex relationships with climate change and associated issues. On the one side, the transportation sector affects climate change by consuming large portions of fuel, therefore contributing to the production of GHG emissions and in turn to air pollution. It also contributes to increased average temperatures, all factors which are largely associated with climate change. On the other side, climate change affects the sector by both damaging transport infrastructure and assets during extreme events and influencing behavioural choices by public and private transportation users (Thomas et al., 2012). A restructure of the transport systems is therefore essential in the national and international policy-making agenda. With the 2011 White Paper Transport, the European Union suggested that sustainable urban transport systems demand for a drastic reduction of vehicles with internal combustion engines and for an increase in urban mobility and infrastructure designs that facilitate walking and cycling (EU, 2011).

According to Gössling (2013), bicycling has fallen since 1950 from a global average of more than 1400 km/person/year to less than 1000 km/person/year. Particularly in industrialized countries, where in 1950 bicycles still represented the most important transport mode, their use has constantly declined since then. Meanwhile, the use of cars as main transportation mode increased to a global average of 2000 km/person/year in the 1990s and an EU27 average of 9490 km/person/year in 2010 (EC, 2012). A study from Lindsay et al. (2010), found that shifting 5% of vehicle kilometres to cycling has highly positive impacts on air pollution as it would reduce vehicle travel by approximately 223 million kilometres each year, save about 22 million litres of fuel and reduce transport-related greenhouse emissions by 0.4%. However, weather and climatic conditions may highly affect choices by people towards active mobility (Thomas et al., 2012). This is also because travel demand results from a complex set of individual travel behaviours in relation to weather and climate conditions, as well as from a range of factors including individual characteristics (income, gender, age, occupation, and vehicle ownership), transportation supply (transport mode options, travel time, reliability, cost, and safety), trip purpose, and temporal factors (time of the day, day of the week, seasonality) (Li et al., 2018).

In this way, any outdoor activity (including active mobility) is influenced by those differences which exist in microclimate and contribute to directly or indirectly shape weather and climate exposure (Helbich et al., 2014). Böcker et al. (2013) conducted a systematic literature review on impacts of everyday weather on individual daily travel behaviour, including cycling. The study found that weather variables such as precipitation, temperature, wind, both singly and in combination, as well as the related perceptions, can highly influence the choice of and the attitude towards active mobility, including cycling. Specifically, warm and dry weather conditions positively influence the use of active modes of transportation, including cycling, whereas rain, snow, windy, cold and hot weather (above 25-30 C) often result in a switch from open-air (including cycling) to sheltered transport modes. Thomas et al. (2013) explored temporal fluctuations of daily bicycle flows on 16 Dutch cycle paths in the period 1987-2003 and found that daily fluctuations in using the paths are described by weather conditions, with the recreational demand being more sensitive to weather than utilitarian demand. Likewise, El-Assi et al. (2017) investigated the relation between weather and bike sharing demand in Toronto (Canada) and found that in the fall season, bike sharing trips were concentrated within the peak morning (24%), peak afternoon (34%) and midday period (22%). As the weather got colder, trip shares in the midday declined in the winter to 19%. The study also revealed a positive correlation between bike share and temperature increase, with the bike share demand being at its highest in a range of perceived temperature between 20 and 30 ˚C. Conversely, bike sharing is negatively correlated with precipitation, snow on the ground and humidity, as they provide unfavourable weather conditions and tend to increase accident or injury risks.

Similarly, Miranda-Moreno and Nosal (2011) found a negative effect by rain on cycling along bicycle paths in Montreal (Canada). Such negative effect was at least more than two times stronger for a bicycle path connecting a low-density residential area, than for a path connecting a less weather-exposed dense residential area. Li et al. (2018) investigated the relation between fluctuation on ridership on bike network (in Nanjing, China) by combining daily ridership data and meteorological data. The study found that precipitation events are more influential than temperature events on daily bike ridership fluctuations. Nevertheless, extremely hot events make bike ridership decrease noticeably in spring, summer and autumn, while large temperature deviation events seem to have the greatest influence in winter by decreasing ridership by 5-9%.

Phung and Rose (2008) report that weather-exposed cycling trails in Melbourne (Australia) have a relatively high optimal riding temperature of 32.5°C (compared to 28°C for other investigated trails). Meanwhile, further studies on Melbourne (Ahmed et al., 2010) also found that extra hours of sunshine decrease the peak period commuter cyclist volumes on some of the bike trails most extensively used for utilitarian purposes. Wadud (2013) detected potentially occurring bicycle flow changes in London on annual, seasonal, and daily basis by developing a negative binomial count-data model and incorporating future projected weather data from downscaled global climate models. Findings reported that an increase in temperature even though tempered by higher rainfall trends, will just lead to a 0.5% increase in the average annual hourly bicycle flows in London's network. However, at a seasonal level, bicycle flows are expected to increase in summer and winter months (+1.6%), decrease in spring (-2%) and being stable in autumn. On a daily basis, leisure cycling will be more affected by a changed climate, with an increase of 7% during the weekend and holiday cycle flows in the summer months.

On a similar vein, Nosal and Miranda-Moreno (2014) investigated the impact of weather on the use of urban bicycle facilities in Montreal, Ottawa, Vancouver and Portland, as well as on the Green Route in Quebec. Primary data were obtained from long-term hourly and daily counts collected automatically using inductive loop detectors and discriminated between utilitarian and recreational count data locations. Findings reported that temperature and humidity are positively and negatively associated with cycling, respectively, and in most of the cases have a non-linear association. Precipitation also had a significant negative impact on cycling flows, and its effects increase with rain intensity. Generally, weather effects appeared being more influential on urban bicycle flows on weekends than on weekdays, and on recreational facilities than utilitarian facilities. Tin Tin et al. (2012) investigated temporal, seasonal, and weather effects on cycle volume (over 220,000 bicycles) in Auckland (New Zealand) in 2009. The study used automated cycle count data and weather data available online from the national climate database. The study found that significant differences existed in mean hourly cycle volumes by hour of the day, day type and month of the year. All weather variables significantly influenced hourly and daily cycle volumes. The cycle volume increased by 3.2% (hourly) and 2.6% (daily) for 1°C increase in temperature, whereas it decreased by 10.6% (hourly) and 1.5% (daily) for 1 mm increase in rainfall and by 1.4% (hourly) and 0.9% (daily) for 1 km/h increase in gust speed. The volume of cycling was 26.2% higher in an hour with sunshine compared with no sunshine and increased by 2.5% for one-hour increase in sunshine each day.

Finally, Böcker and Thorsson (2014) investigated and compared the effects of different meteorological variables, both singly and combined, on cycling frequencies, cycling durations, and the exchange between cycling and other transport modes. The study was based on travel diary data from a panel study of 945 respondents from the metropolitan area of Rotterdam (the Netherlands). Findings revealed the negative effects of precipitation sum and wind speed and nonlinear bell-shaped effects of thermal variables on cycling, while the opposite was found on car usage. It was also found that variables such as the mean radiant temperature (radiant heat exchange between humans and the environment) and physiological equivalent temperature (an index combining the effects of air temperature, mean radiant temperature, air humidity, and wind speed) are more influential on behaviour than just air temperature. Optimum thermal conditions for cycling were found on days with maximum air temperatures around 24.8 ˚C.

## 3.4. Demonstration Case: Emergency Planning

The demonstration case of emergency planning will take place in the city of Antwerp. The Disaster Management Department of the City of Antwerp is responsible for the planning and management of different types of disasters on the territory of the city, including those related to extreme weather such as heavy rainfall, flooding, hail, and wind storms. For the City of Antwerp, an Emergency Planning service is proposed that will deliver: (1) changes in the frequency of extreme rain storms and pluvial floods, and related changes in the pluvial flood risk areas, (2) quantified impacts on the disaster emergency planning, (3) revised traffic routes depending on the inundated areas. This will lead to a climate-proof emergency plan for extreme rainfall and pluvial flood-related disasters. A tool will be implemented to quantify the socio-economic consequences of pluvial inundation, using readily available spatially referenced land use data (locations of houses, hospitals, schools, traffic infrastructure such as tunnels, elderly home). Inundation information will be coupled to (existing) traffic models to assess the impacts on disaster emergency planning needs (interventions by the fire brigade, police, ambulances; evacuations), and to compute alternative emergency traffic routes.

### 3.4.1. Hazards, vulnerability and emergency planning

Climate change is key in shaping urban planning activities, including emergency planning. Indeed, urban planning needs to include various aspects of climate change response, including preparedness, emergency management, or adaptation (Wilson, 2006; Prabhakar et al., 2009; Measham et al., 2011; Nalau et al., 2015). Emergency management and planning typically involves four main components (Golnaraghi, 2012), including:

- Detection, monitoring and forecasting of hazards (Hazard Data and Forecasts);
- Risk assessment and development of comprehensive risk warning messages (Risk Information);
- Information dissemination in a clear, timely and reliable way (Communication and Dissemination Mechanisms);
- Activation of emergency plans to reduce the impact on lives and livelihoods (Preparedness and Early Response).

Pluvial or flash floods are usually caused by extreme local rainfall which outweighs the urban drainage potential causing surface water floods or flash floods. These events occur within a time lag of a few hours or even less and typically affect a small area (Gaume and Borga, 2008; Norbiato et al., 2008). Consequences include loss of human lives, material damage, as well as emotional well-being of individuals and their health (Van Ootegem and Verhofstadt, 2016). For the period 1950-2006. Barredo (2007) reported that major flash flood events in the European Union caused 2764 fatalities - i.e., 52 casualties per year on average. Similar figures are found for the US by Ashley and Ashley (2008).

Investigating flash floods is difficult due to a lack of systematic observational data, encompassing data on the flood-generating rainfall at the required space and time detail and discharge data. Observation of rainfall at fine-scale remains a challenge. Precipitation is traditionally measured with rain gauges which collect the amount of rainfall at a given location. These measurements are relatively accurate but only represent precipitation at a given point. Indeed, the spatial variability of the precipitation field is generally very large which means that the spatial representativity of rain gauge point measurements is relatively low (Ochoa-Rodriguez et al., 2015). In such situations the spatial structure of precipitation can only be captured using weather radars and related operational services. These radars typically produce rainfall observations with a spatial resolution of 1 km and a time step of 5 minutes, however they only provide indirect measurements of precipitation as well as radar-based rainfall estimations are affected by various sources of uncertainties (e.g. Berne and Krajewski, 2013). A careful processing of the data and a merging with rain gauge measurements is required to derive quantitative precipitation estimates from radar observations (e.g. Goudenhoofdt and Delobbe, 2016; Thorndahl et al., 2018).

To propagate the quantitative precipitation estimates to urban pluvial flood hazard maps, dynamic models are typically used, solving the appropriate approximation of mass and momentum conservation shallow water equations, integrate detailed process descriptions covering a wide range of flow patterns (Hunter et al., 2008; Néelz and Pender, 2013). The application of dynamic models for urban flooding, however, remains a challenge due to prohibitive computational times and scarcity of available data to calibrate the models. Nonetheless, it has been shown that optimal approaches accounting for modelling objectives, different sources of in-situ data, catchment characteristics and computational demands can contribute to solve some urban drainage challenges. Traditionally, urban drainage models only describe the underground system, by solving the one-dimensional (1D) full St Venant equations. Urban flood modelling, however, requires such models to be extended or linked to a surface inundation model. This allows the storm water drainage to be described both in the underground system and the surface system. That is why this modelling approach is also called dual drainage method. The surface system model in this method can be zero-dimensional (0D), 1D or two-dimensional (2D). While all of them present strengths and uncertainties, the 1D-2D approaches involving the coupling of the 1D underground models with a full 2D model for the overland flow (Seyoum et al., 2012; Simões et al., 2011; Pina et al., 2016; Yu et al., 2016) are widely applied as evidenced in various software packages and a range of studies (Jahanbazi and Egger, 2014; Willems et al., 2016; Ntegeka et al., 2016; Bermúdez et al., 2018). This is because they are considered more physically based especially regarding the way flow conditions on the surface are conceptualized.

The urban pluvial flood hazard maps can be transferred into flood risk maps by considering the flood consequences, e.g. the economic flood damage. Most of the studies analysing damage caused by floods focuses solely on the impact of the depth of the flood (e.g. Ernst et al., 2008; Pistrika and Jonkman, 2010; De Moel and Aerts, 2011). However, socio-economic factors are also key (Messner and Meyer, 2005; Van Ootegem et al., 2015). In particularly, socio-economic susceptibility indicators, such as the individual and public preparedness for floods and the quality of the coping strategies, can limit the damage caused by the flood. For example, with respect to floods of the Elbe individual awareness led to a reduction of the damage of 5-30% (DKKV, 2004). For pluvial floods in Flanders, Van Ootegem et al. (2015; 2018) find that more awareness led to a reduction of the damage by 77% to 90%, depending on which part of the house was flooded.

Factors such as knowledge and experience of the hazard have also a significant impact on the individual response (Van Ootegem et al., 2015; 2018). This indicates that the population which is most at risk needs to be well informed on the risks and precautionary measures to minimize the damage. Furthermore, socio-economic factors that are a measure of the social network of individuals (e.g. family size, kin relations (number), community involvement, ethnic group member, socio-economic status) have a significant impact on the response of individuals. This shows that it is crucial to know whom to communicate the hazard and risk information and to ensure coordination between national, regional and local emergency workers.

An effective communication of the hazard and risk information should clearly describe the physical hazard to individuals and clearly define why it is a threat (Drabek, 1999). In case the message is too vague, individuals give their own interpretation, which may complicate the response (Mileti and Peek, 2000). Therefore, studies should clearly report on the exact nature of the hazard and the consequences of action or inaction (Mayhorn and McLaughlin, 2014). This includes a description of the physical boundaries for the location where individuals are located who need to take precautionary measure (King, 2008). In addition, those that are not directly at risk on the hazard locations have to be informed, so that they know which places to avoid. In this perspective, several studies underline the importance of maps as a useful communication tool to convey information in a comprehensive manner (Dransch et al., 2010). They should be accompanied by a number of precautionary measures that the individuals should perform to minimize the impact of the flood on their health and safety. The message should include detailed information on how to exactly perform these actions and when individuals should start and complete these actions. Mileti and Darlington (1999) indicate that including detailed information on precautionary measures in the hazard communication, increases the resilience of individuals, but also increases the responsiveness.

Preparedness relates also to the willingness of citizens to participate in taking private protection measures. In a survey on Dutch households' perceived responsibility for taking private protection measures (Terpstra and Gutteling, 2008), 73% of the respondents consider the government as primarily responsible for protection against flood damage, while 50% viewed disaster preparedness as an equal responsibility between themselves and the government. However, in practice it appears that although individuals are aware of the importance of private protection measures, only few undertake activities to mitigate future losses. For example, survey evidence from Germany, Norway, Sweden and the UK indicates that more than 80% of all respondents have not undertaken any steps to mitigate future losses (Krasovskaia, 2005). Terpstra (2010) find similar figures for the Netherlands. By using 2002 and 2006 data, Kreibich et al. (2010) find that in Germany, in 2002, preparedness of households to take precautionary measures was very low: 30% of the households and 54% of the businesses interviewed did not take precautionary measures. Moreover, only 26% of the households knew how to react when the flood warning was issued and only 9% of the businesses had an emergency plan in place. In contrast, 90% of the households and 71% of the businesses were prepared for the flood in 2006. This learning experience may have an important impact on the level of damage as shown by the study of Van Ootegem et al. (2015), who finds that having experienced a flood before decreases the building damage by 16%.

### 3.4.2. Emergency planning and preparedness

According to Mehiriz and Gosselin (2016), emergency response to weather-related hazards also depends on proactive and preventive measures undertaken before the event to protect population, properties, and critical public infrastructure (see also ten Brinke et al., 2010 and Sciulli et al., 2015 for Europe). In urban areas, emergency management depends on the preparedness level of local governments, which consists of the institutional framework, the risk of extreme weather-related hazards, and the proper preparedness capacity. The institutional framework (e.g., policy, planning, and regulations) provides the incentives, obligations and resources for local decision-makers. The risk of weather-related disasters is the result of the interaction between the risk of exposure and the vulnerability to extreme weather events. The preparedness capacity is defined as the ability to acquire human, financial, material and information resources which are required for the implementation of effective emergency management services. Emergency response, therefore, results from the combination of preparedness, risks of weather-related disasters, and the quality of information held by emergency management services. Particularly, information in this case includes effective warning systems which provide reliable and on time information on extreme weather events and related forecasts and preparedness. Likewise, information needed by users about individual and community exposure and vulnerability is also part of information for emergency response. Surveys among emergency managers have found that most of them assess a positive response to an emergency when high quality of weather warning exists. Therefore, the implementation of an effective early warning system, or the improvement of the existing one, is key to emergency managers for providing a more effective response. This also contributes to improve governance through more effective and collaborative networks among stakeholders from the institutional organizations, as well as practitioners, market actors, and local communities (Mehiriz and Gosselin, 2016).

## 3.5. Demonstration Case: Cultural Heritage

The last demonstration case is Cultural Heritage, which will be investigated in the city of Rome. Specifically, the technical partners will closely work with the Special Superintendence of Rome

(*Soprintendenza Speciale Archeologia, Belle Arti e Paesaggio di Roma*) (SSBAR) that is an organisational structure of the Italian Ministry of Cultural Heritage and Tourism and has the objective to preserve and promote the archaeological heritage of the City of Rome. A specific focus will be the development and protection of the area enclosed by the ancient Aurelian Walls and a few other sites outside the walls. It is necessary to enhance capacities for coping with the effects of climate change (particularly increased heat stress and extreme rainfall) that is expected to damage fragile materials from intense precipitation but also to worsen the conditions for touristic activities. The service to be developed will provide the Special Superintendence with information on climate change impacts on different archeological sites for better planning the investment and adaptation actions for each of them and will provide tourists visiting Rome with indications for planning their visits to archeological sites reducing their exposition to heat or other climate-related discomforts.

### 3.5.1. Climate change and the tourism sector

According to Scott et al. (2012), climate change can affect both current and future tourism trends in four main ways, as follows:

- direct climatic impacts that alter the length and quality of climate-dependent tourism seasons, operating costs, location decisions and design, infrastructure damage and business interruptions, destination attractiveness, and tourist demand and destination choice
- indirect climate-induced environmental change that affects natural assets that define destination image and are critical attractions for tourists, environmental conditions that can deter tourists, operating costs and the capacity of tourism firms to perform a sustainable business
- indirect climate-induced socioeconomic change such as decreased economic growth and discretionary wealth, increased political instability and security risks, or changing attitudes toward travelling
- and, policy responses of other sectors that could alter factors relevant for the tourism sector such as the cost of transport, water rights, or insurance costs.

Furthermore, climate change can also have potential impacts on tourists' decision-making, including motivations, destination choice, timing of travel, and experiences, with potentially positive and negative consequences for tourism attractions, sites, or locations (Becken, 2010). Therefore, changes occurring in the spatial and temporal distribution of climate resources will have relevant effects for tourism demand (Gössling et al., 2012). On this regard, tourists expect certain climatic conditions when they travel to a place. Therefore, their choice can also be driven by meteorological forecasts or by recent climatic trends. However, at the tourism destination tourists experience a weather which might deviate from the average conditions or from their expectations. In this way, tourists and tourism businesses are likely to be affected by weather conditions, including heatwaves, floods, and rainfalls (Becken, 2010).

The response by tourists to the complex set of climate change policies (mitigation and adaptation) at multiple scales, the large set of climate change impacts on destinations, as well as broader impacts on society and economic development are those factors which influence the climate change impacts on tourism demand patterns. Tourists have the largest adaptive capacity of elements within the tourism system because of their flexibility to substitute the place, timing and type of holiday, even at very short notice. The anticipated impacts include a gradual shift in international tourism demand to higher latitude countries. Relative demand

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for international travel to sub-tropical and tropical nations is projected to decline. However, global scale simulation models of tourism demand are necessarily highly simplified and have important limitations, including a wide range of tourist-response related uncertainties (Gössling et al., 2012).

### 3.5.2. Climate change and cultural heritage

Cultural heritage is one of the most threatened resources for the tourism sector, however relatively little attention has been posed on direct and indirect impacts from climate change (Fatorić and Seekamp, 2017). Several cultural heritage sites are located in tourist destinations, and some are among the most iconic places on Earth (Markham et al., 2016). According to Article 1 of the United Nations Educational, Scientific and Cultural Organisation Convention (UNESCO), cultural heritage includes "moveable tangible heritage items such as paintings, sculptures, coins and manuscripts; immovable heritage such as monuments, archaeological sites and underwater cultural heritage such as shipwrecks, underwater ruins and cities; and intangible items such as oral traditions, performing arts and rituals". Therefore, cultural heritage represents valuable social and environmental features which humanity preserves from the consequences of development and decay and contributes to develop a sense of connection between individuals, the community, the surrounding environment, and past and current lived experiences (McIntosh and Prentice, 1999).

Climate change poses serious direct and indirect threats to the protection, preservation, and transmission of this non-renewable cultural heritage to future generations, therefore presenting a threat to its outstanding universal value, integrity and authenticity (Cassar and Pender, 2005; Haugen and Mattson, 2011; Fatorić and Seekamp, 2017). Climate change multiplies and accelerates threats and contributes to increase vulnerability and exacerbate other stresses including those deriving from pollution, conflict, overexploitation of resources, urbanization, and habitat fragmentation. The speed of climate change can also severely limit ecosystem response worldwide, and it might require the adoption of new management practices (Markham et al., 2016). These impacts do not affect just the economic value of the item, but also the important individual and collective social and cultural aspects of cultural heritage (Maus, 2014; Hall et al., 2016). Indeed, as stated by Hall et al. (2016), climate change is experienced within a variety of cultural contexts and the elements that are intertwined with heritage preservation are complex and may be easily misunderstood by those outside of a specific culture.

Hall et al. (2016) identify four specific areas of potential and observed threats from climate change on cultural heritage: cultural landscapes, the built environment, buried archaeology, and parks and gardens. Several studies identify climate change as rapidly becoming one of the main significantly threatening factors for cultural heritage worldwide (Markham et al., 2016). These factors include the impacts of atmospheric agents on structures and materials of historical buildings and/or monuments (e.g., Bonazza et al., 2009; Brimblecombe et al., 2010; Balica et al., 2012) and archaeological sites (Grossi et al., 2007), and on the indoor climate of historic buildings (e.g. Leissner et al., 2015), as well as the impacts of hydro-meteorological extreme events on traditional landscapes (e.g., Dupont and Van Eetvelde, 2013), underwater sites (e.g., Perez-Alvaro, 2016), and UNESCO world heritage (e.g., Marzeion and Levermann, 2014).

The effect that atmospheric agents have on buildings, sites, and landscapes are recognized. For example, climate change is likely to give rise to more wet-dry cycles that will contribute to accelerate the crystallisation of salts in stone- and brick-constructions. Also, further risk of biological degradation exists due to wood moisture exposure, especially where there has not earlier been critical moisture stress (McIntyre-Tamwoy, 2008; Pearson, 2008; Kaslegard, 2011). A milestone work from Brimblecombe et al. (2010) claimed that atmospheric agents impacting on cultural heritage can be categorized in three distinct groups: 1) temperature-derived parameters (range, freeze thaw, and thermal shock); 2) water-derived parameters (precipitation, humidity cycles, and time of wetness); and 3) wind-derived parameters (wind, wind drive rain, sand and sault).

In terms of 1) temperature-derived parameters, slow changes in temperature have the potential to affect large cultural heritage buildings through e.g. seasonal change, as structure can change in response to the annual variability of temperatures. Furthermore, frost can damage wet porous building stone. Also, during a period when the seasonal temperature only changes slightly, there can be a very significant change of freeze-thaw cycles. This emphasizes the way in which small changes in meteorological parameters can be amplified and have effects on building materials. In terms of 2) water-derived parameters, temperature can influence some aspects of the water balance and humidity in relation to outdoor materials. Hydrometeorological parameters relevant for impacts on cultural heritage include: extreme precipitation events; saturation of soils and water loading on roofs and other architectural elements. For most materials, an increasing relative humidity causes an increase in the deterioration due to a prolonged time of wetness, higher deposition rates of pollutants, and more favourable conditions for microbiological activities. Intense and more frequent rainfalls have the potential to overload roofs and guttering in turn contributing to local surface flooding. This can represent a problem for cultural heritage items and particularly for vernacular architecture constructed on unfired material including wattle, daub, or cob. Precipitation can also affect the damage of wet deposition by dissolution of surface layers of materials. Erosion and deliver of acidity are important aspects of the role played by precipitation. Changes in the chemical composition can affect the deterioration rate of building material too. In summers, less precipitation and less relative humidity can affect the material, e.g. by damaging stone material through salt intrusion and related chemical processes. Increasing temperatures and lower rainfall rates in summers also imply changes in evaporation and reduction of soil moisture contents. Drier conditions can lead to an excessive desiccation of unfired buildings, with implications on building foundations and archaeological sites. Finally, in terms of 3) wind-derived parameters, wind can cause parts of buildings to fail or collapse. Also, given that high winds blow rain almost horizontally, there is the potential for wind-driven rain logging into the fabric of buildings. In coastal areas, wind can drive salt into the fabric, generating or exacerbating processes of abrasion and erosion of materials. Changes in wind can also increase the deposition rates of gaseous and particulate pollutants; for example, excessive deposited diesel soot on facades can disfigure the building.

## 4. Socioeconomic Impact Assessment: An Overview of Methods

Impact assessment refers to a suite of methods employed for analysing and understanding the potential range of impacts by a project occurring to society, and the related responses of those impacted by the project. Impact assessment contributes to inform strategies to minimise negative impacts and/or maximise positive impacts of any project. Impact assessment methods both determine the full range of impacts (e.g. in terms of income, employment, access to services, quality of life) and evaluate the social, environmental, economic, and technological implications of each specific project (Bellini et al., 2016). Social impact assessment and economic impact assessment are often undertaken separately and employ specific methods, but recent development and application of projects employ these assessments in a complementary, and sometimes overlapping, way. This highlights the necessity for collecting and analysing both qualitative and quantitative data to comprehensively cover all the relevant emerging themes.

According to Berghout and Renkema (2001), socioeconomic impact assessment methods vary according to the level of detail, the considered range of stakeholders, and the specificities of the needed data. Galliers and Land (1987) argued that the selection of an appropriate assessment method for research projects is based on the suitability of the method and the rigour of its development and application, and it is key for ensuring the process is accurate and successful in its wholeness. In this way, a set of matrices is necessary to match project characteristics and evaluation techniques and to identify a suitable method. Numerous factors influence the selection of the appropriate method for impact assessment, including social and organisational contexts, the organisational domain, the level of analysis, objective and perspective of the assessment, purpose of the investment, measurability of system impacts, and application (Monacciani et al., 2011). Several metrics are required for the assessment of projects and all their components. For example, De Jong et al. (1999) categorised techniques into fundamental measures, composite approaches and meta approaches, while Lech (2005) discussed financial techniques and qualitative methods such as multi-criteria methods, strategic analysis methods and probabilistic methods.

Among the others, Renkema and Berghout (1997) categorised four main approaches, that are the financial approach, the multi-criteria approach, the ratio approach and the portfolio approach. Methods from the financial approach are usually employed for the evaluation and selection of corporate investment proposals. These methods are based on the incoming and outgoing cash flows resulting from the investment made, and include e.g., the payback period, the internal rate of return, or the net present value. Methods from the multi-criteria approach create one single measure for each investment and are used in many decision-making problems. Before using a multi-criteria method, a number of goals or decision criteria have to be designed. Scores have then to be assigned to each criterion for each considered alternative. Likewise, the relative importance of each alternative should be established by means of weights. The final score of an alternative is calculated by multiplying the scores on the different decision criteria with the assigned weights. Methods from the ratio approach allow comparing organizational effectiveness by means of ratios. Examples of meaningful ratios are: expenditures against total turnover and all yields that can be attributed to investments against total profits. Ratios do not necessarily take only financial figures into account. For example, expenditures can be related to the total number of employees or to some output measure (e.g. products or services). Finally, methods from portfolio approaches are used in strategic analysis projects, for example by plotting investment projects against several evaluation criteria (Renkema and Berghout, 1997). Literature provides other classifications, but they are not mentioned here. These classifications sometimes overlap, as well as differences exist between them. In this way, adopting a commonly accepted and coherent method for socioeconomic impact assessment can be difficult (Monacciani et al., 2011).

## 4.1. Main methodologies to be used in the impact assessment framework

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The topic of climate services is reasonable new and can be declined in different ways and applied to different sectors; for this reason, at the present stage there is not a standard for assessing the impact of climate services. Moreover, to map and describe socioeconomic impacts of climate services in diverse urban contexts a single methodology is not sufficient and a mixed method approach is needed. The development of the methodology described in the next paragraphs rely on literature, but also on the previous experience in European research projects running innovative endeavours in other sectors. In this sense the SEQUOAI methodology represented a useful starting point (Passani et al., 2014). SEQUOIA and following projects adopted a combined use of different techniques in order to overcome the limits of each single assessment method (i.e. collection of statistical data, case studies, peer review, cost-benefit analysis, multi-criteria analysis (MCA), input-output models, etc.) and in order to gather quantitative and qualitative data within the same analytical framework. In this way, a set of methods to be potentially applied for socioeconomic impact assessment has been considered for Climate-fit.city and includes:

- Return on Investment (RoI)
- Cost-Benefit Analysis (CBA)
- Cost-Effectiveness Analysis (CEA)
- Multi-Criteria Analysis (MCA)
- Willingness to Pay (WTP)

Below, the selected methods are presented and synthetically described.

### *Return on Investment (RoI)*

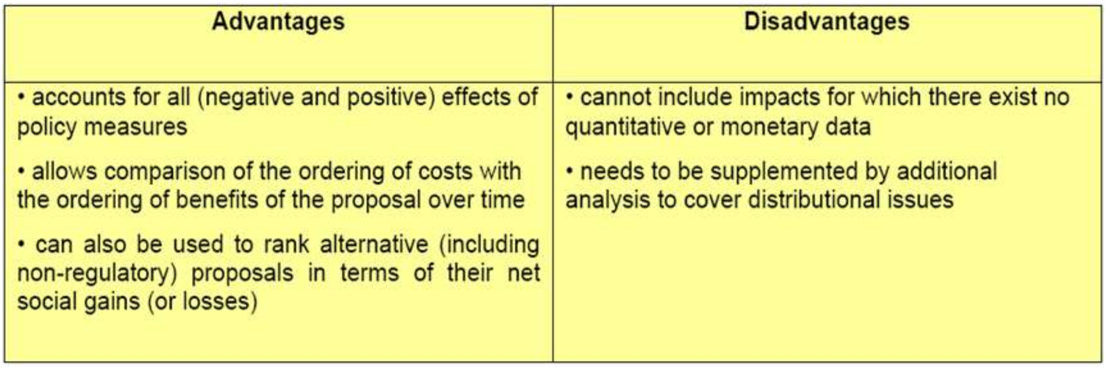
Return on Investment (RoI) is a traditional financial method which is frequently used to compare alternative investment strategies. RoI assesses options for investments to detect the one which expects the highest return from the investment. For example, a company might use RoI as a factor when deciding whether to invest in developing new technologies or extending the capabilities of the existing technology (Sonnenreich et al., 2006). To calculate RoI, the cost of a purchase is weighed against the expected returns over the life of an item. Nevertheless, RoI presents some limitations. For example, RoI is based on subjective elements, such as the harmonisation methods of the accounting. Also, it often has a narrow project focus, with the potential risk of overlooking cross-functional system impacts. In addition, RoI might not consider potentially emerging intangible costs/benefits and the social and organisational contexts in which RoI is applied (Carcary, 2008).

### *Cost-Benefit Analysis (CBA)*

Cost-Benefit Analysis (CBA) is a comprehensive and theoretically sound method of economic evaluation which has been extensively used to support decision-making in many different areas of social and economic policy and project management (Robinson, 1993). CBA involves (explicitly or implicitly) weighting the total expected costs against the total expected benefits of one or more actions to choose the best or most profitable option. CBA aims to express in monetary values both the inputs (costs) and outcomes (benefits) of a policy or a project. This also enables the monetary returns on investments to be compared with the returns obtainable from investments in other areas of the economy (Robinson, 1993).

All flows of project costs and benefits, and therefore impacts, tend to occur at different points in time and are expressed on a common basis in terms of their "present value". CBA involves comparing acquisition, implementation and operational and on-going costs with the benefits arising from the system's practical usage. This is generally performed on a marginal costing basis, i.e. only marginal or additional costs are included and compared to each other. At the same time, only marginal benefits are considered to prevent double counting of costs or benefits. These costs-benefits values can be displayed as annual cash flows, while expected returns can be calculated by e.g. using RoI techniques (Carcary, 2008).

CBA is suitable when the most significant project costs and benefits can be measured in monetary terms and the expected social and economic outputs can be assessed. Relevant costs and benefits of all options for government and society should be valued, and the net benefits or costs should be calculated. Relevant costs and benefits vary depending on the scope and the nature of the project, but in the initial steps of the project broad considerations are required about its potential costs and benefits. These costs and benefits should be normally based on market prices as they reflect the best alternative uses for goods and services, that is the opportunity cost (HM Treasury, 2018). However, given that not all goods and services have a market price, costs and benefits should therefore be estimated by a proxy (Monacciani et al., 2011; HM Treasury, 2018). Costs can also be assessed for example as Full Time Equivalent costs, which include the opportunity cost of labour in terms of the total value of the output produced by employees (e.g. time, pension, insurance, allowances, benefits and basic salary) (HM Treasury, 2018).

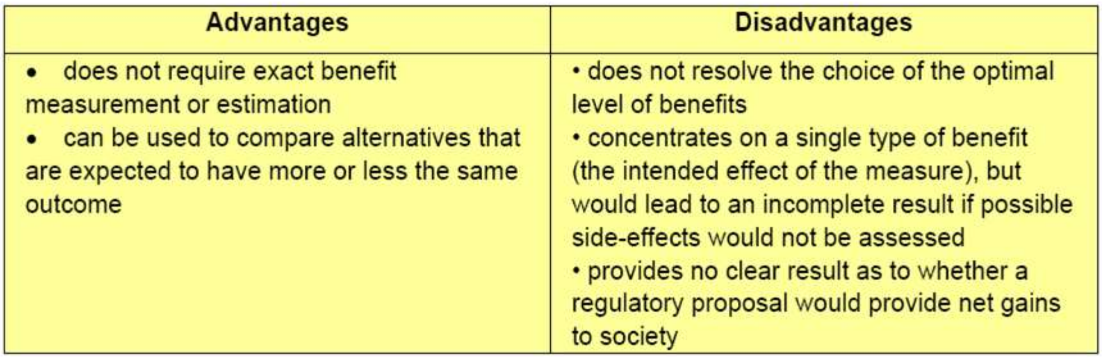


| Advantages | Disadvantages |
|---|---|
| • accounts for all (negative and positive) effects of policy measures<br>• allows comparison of the ordering of costs with the ordering of benefits of the proposal over time<br>• can also be used to rank alternative (including non-regulatory) proposals in terms of their net social gains (or losses) | • cannot include impacts for which there exist no quantitative or monetary data<br>• needs to be supplemented by additional analysis to cover distributional issues |

*Table 1 - CBA: advantages and disadvantages. Source: European Commission (2009, p. 45)*

### *Cost-Effectiveness Analysis (CEA)*

Cost-Effectiveness Analysis (CEA) is a variant of CBA which compares the costs of alternative ways of producing the same or similar outputs. This method can be used when the investment/project has an already fixed objective. CEA aims to calculate the costs necessary for the achievement of the fixed objective and the selection of the preferred options that allow reaching the goal with lower costs. CEA may sometimes be appropriate where wider costs or benefits will remain broadly unchanged or for the delivery of a public good, such as defence, as well as where output may not be proportionately quantified (HM Treasury, 2018).

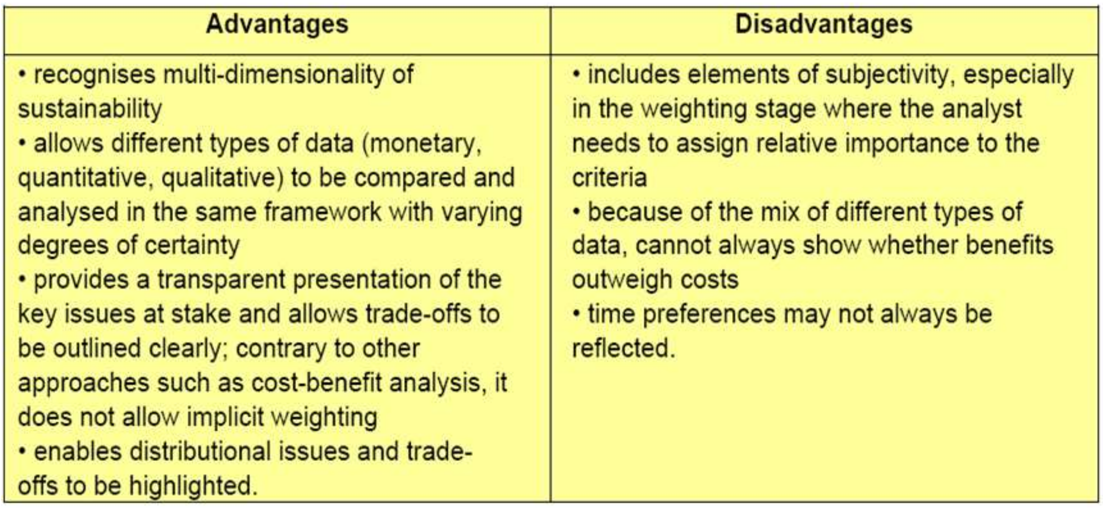


| Advantages | Disadvantages |
|---|---|
| • does not require exact benefit measurement or estimation<br>• can be used to compare alternatives that are expected to have more or less the same outcome | • does not resolve the choice of the optimal level of benefits<br>• concentrates on a single type of benefit (the intended effect of the measure), but would lead to an incomplete result if possible side-effects would not be assessed<br>• provides no clear result as to whether a regulatory proposal would provide net gains to society |

*Table 2 - CEA: advantages and disadvantages. Source: European Commission (2009, p. 46)*

### *Multi-Criteria Analysis (MCA)*

Multi-Criteria Analysis (MCA) techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities (Department for Communities and Local Government, 2009). Its versatility allows MCA to cover a wide range of different methods, including structured, formative, semi-subjective and socio-political methods that recognise that there are alternative measures to monetary values. Qualitative and quantitative decision criteria are assessed through weighted scoring (Carcary, 2008). This analysis allows aggregating positive and negative impacts (both usually qualitative) into a single tool in order to easily compare different impacts of different scenarios.



| Advantages | Disadvantages |
|---|---|
| • recognises multi-dimensionality of sustainability<br>• allows different types of data (monetary, quantitative, qualitative) to be compared and analysed in the same framework with varying degrees of certainty<br>• provides a transparent presentation of the key issues at stake and allows trade-offs to be outlined clearly; contrary to other approaches such as cost-benefit analysis, it does not allow implicit weighting<br>• enables distributional issues and trade-offs to be highlighted. | • includes elements of subjectivity, especially in the weighting stage where the analyst needs to assign relative importance to the criteria<br>• because of the mix of different types of data, cannot always show whether benefits outweigh costs<br>• time preferences may not always be reflected. |

*Table 3 - MCA: advantages and disadvantages. Source: European Commission (2009, p. 47).*

In Climate-fit.city we will use MCA not for decision-making purposes, but as a structured framework in which keeping together and quantifying as much as possible qualitative and quantitative data and impacts expressed in monetary terms with those that cannot be expressed in monetary terms. As it will be reported in the next chapter, some indicators will be applied in all the demonstration cases, but they do not have the same relevance for all of them. For this reason, we will develop an ad hoc weighting matrix. Project partners have been already asked to score the relevance of the different areas of impact under analysis, but this activity will be further refined in the next months by scoring each single variable of the different areas of impact. In this way, each demonstration case will have a personalised methodology able to reflect its peculiarities.

*Willingness to Pay (WTP)*

Willingness to Pay (WTP) can be generally described as the maximum price a consumer would be willing to pay for a given quantity of a good or service (Smith and Nagle, 2002). WTP represents therefore the main baseline for any business when pricing their goods or services. Indeed, when a business has no adequate knowledge of the customer's WTP for its products, it can easily fail to develop a pricing strategy that is suitably customized to its marketing environment and could therefore ignore relevant sources for increasing profitability of the offered products. Minor variations of prices and the corresponding consumer behaviour can also have notable effects on revenues and profits (Breidert et al., 2006). In the Climate-fit.city project, WTP will be employed in order to understand how much stakeholders, and particularly those in the public sector, would be willing to pay for customizations and updates of the climate services as provided by the project.

After having provided an overview of the selected methodologies to be used for conducting socioeconomic impact assessment, it must be pointed out that given the range of the actual and potential socioeconomic impacts, of the variety of climate services to be provided into the project, and of the related variables to be considered, all the selected methods will be applied in a highly flexible way, to be adaptable to the complex nature of the investigated topics. It is also necessary underlining that impacts of the climate services proposed will occur only if the developed service and the relative information provided will be exploited for leading to changes and improvement into multi-scale institutional policies, or to revised organizations' processes and practices.

A further and last point to be raised is that we are aware that all the range of provided climate services into this project potentially also have impacts on climate change adaptation options. These impacts are usually assessed through several methodologies which are able to compare different scenarios describing the situation with and without a specific adaptation option or a set of options. These methodologies consider a range of social and economic aspects of adaptation which can be impacted by the selected services at different levels and scales. These methodologies are based on methods including - but not limited to - general and macroeconomic methods (e.g., Scenario-Based Impact Assessment, Computable General Equilibrium, and Global Economic Integrated Assessment Model) or methods weighted for the specificities of each economic sector (e.g., tourism, housing market) (see among the others Steininger et al., 2015; Toeglhofer et al., 2012; Prettenthaler et al., 2016).

Scenario-Based Impact Assessment (SBIA) is an approach that combines climatic model outputs with sector impact models (or functional relationships) to estimate physical impacts, which are then valued to estimate welfare costs. The advantage of this approach is its potential to be applied to market and non-market (e.g. health) sectors at various levels. However, it is not able to grasp cross-sectoral and economy-wide effects. Specific variations to SBIA also exist and include e.g. risk assessment, which focuses on extreme (probabilistic) events such as floods by using historical analogues or damage-loss relationships, or econometric based assessment, which rather uses historical relationships between economic production and climate to be successively applied to future climate scenarios (see Watkiss, 2015, and references therein).

Computable General Equilibrium (CGE) approach represents a multi-sectoral and macro-economic analysis of the economic costs of climate change. It allows capturing cross-sectoral linkages and economy wide effects (and metrics) and can investigate price and trade effects.

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However, impacts are described as an aggregate and their analysis does not include non-market impacts (see Watkiss, 2015, and references therein). CGE methods are very useful for assessing economywide feedback effects of "local" shocks, such as sectorial impacts by climate change. Nevertheless, they are less useful in depicting dimensions and impacts which are less tangible, for example those on human health or welfare, that inevitably adaptation touches upon. Furthermore, CGE approach is generally not able to detect changes occurring in stocks. For example, impacts calculated in terms of GDP (flow) portrait the impact of climate change on the economy's ability to produce goods and services, but do not capture the impacts on stocks, which might be higher. In this way, CGE approach requires further adequate adjustments to be able to capture more diverse variables (Bachner et al., 2015).

Global Economic Integrated Assessment Model (GEIAM) approach estimates the economic costs of climate change, by using highly aggregated economic damage functions, and is usually based on global temperature increase as aggregated climate parameter. GEIAM can be utilized to provide total net present values for future damages over time and to estimate the marginal social costs (e.g., the damage cost of extra GHG emissions) (see Watkiss, 2015, and references therein). GEIAM presents however limitations, such as the arbitrary choice of damage functions, the neglect of catastrophic outcomes, and the deep uncertainty around climate sensitivity that is not considered into GEIAM. Additionally, the regional sensitivity of various damaging climate parameters (precipitation patterns and intensity, storm frequency/amplitude, heat wave distribution etc.) to increasing global temperatures cannot be reflected adequately in integrated global models (Steininger et al., 2015).

While the suitability of these methods has been demonstrated in analysing the impact of climate change and related adaptation strategies, they do not fit with the purpose of the impact assessment for Climate-fit.city services as their application at the local level will take very different forms that are not predictable at the current stage. Nevertheless, these methods could represent a further opportunity for the assessment of projects' outputs and results and could be applied in the future along all the lifetime of the project if -and when- the use of the Climate-fit.city services will generate clear adaptation measures and plans in the urban areas represented in the project.

The next chapter identifies main areas of impacts, sub-dimensions, selected methods and data gathering processes for each of the demonstration cases based on the assumption of their full exploitation.

## 4.2. Ex-ante and ex-post socioeconomic assessment for the project

In the Climate-fit.city project, the socioeconomic impact assessment will be based on an ex-ante/ex-post comparison. More specifically, the assessment will compare the situation before the climate service is developed in each demonstration case (ex-ante) with the situation after its development and its potential usage (ex-post). This will allow to have a portrait of the status quo *without* the proposed climate service, to be compared with the scenario *with* the implemented climate service. This means that data gathering will be necessarily occur in two rounds. The development of the ex-ante scenarios will be done with the support of the partners responsible for the demonstration cases and will rely as much as possible on available datasets and information, while for the ex-post scenario ad hoc data gathering activities will be needed. The comparison between the ex-ante and the ex-post socioeconomic impact assessment will demonstrate the improvements caused by the project through its output(s) in comparison with the current situation. This makes socioeconomic impact assessment as a suitable set of methods to be applied for the aims and objectives of the Climate-fit.city project.

# 5. Impact assessment methods for the Climate-fit.city demonstration cases

## 5.1. Climate and Health

The provided service for Climate and Health is expected to lead to a vast range of socioeconomic impacts. Significant impacts are expected in the area of public health, where key sectors for responding to heat-waves emergency are the early warning system and the hospital response. Among the others, improvements are expected in terms of coordination among the potential range of intervening stakeholders (e.g., meteorological offices, hospitals, early warning systems respondents, and so on). This would lead to a more coordinated and timely early warning system, as well as it will improve the hospital response, for example by improving emergency procedures or providing more organized medical assistance. Impacts are also expected in terms of cost saving, as a number of lives are expected to be saved. Meanwhile, GHG emissions abatement would be also achieved. All these expected impacts would lead towards a better functioning of public administration and an improved health for citizens. Additional impacts are expected on a vast range of policies including health, transport, or social policies. Finally, the proposed climate service will impact on citizens' wellbeing, as intervening on emergency planning will contribute to a better protection of those groups of citizens which are more vulnerable to heat waves and will increase equality at social level.

Accordingly, socioeconomic impact assessment would assess impacts by the provided service in terms of effectiveness of key services the public sector is in charge for in case of heat waves, such as early warning systems and hospital response. In this way, MCA will be applied for impact assessment. Meanwhile, positive economic impacts are expected on the public health system and therefore CBA will be employed to assess the cost saving due to saved lives and reduced required medical assistance. Furthermore, MCA will be performed for conducting socioeconomic impact assessment of the already implemented policies (e.g., health, transport, or social). For policies still under development, key stakeholders will be also deeply involved into the assessment.

| **Areas of impact** | **Sub-dimension** | **Method to be applied** | **Data gathering process** |
|---|---|---|---|
| Impact on public service efficiency and effectiveness | Effectiveness of early warning system | MCA | Ex-ante: analysis of available data (warning system procedures and performance). Ex-post: interview to key stakeholders or focus groups |
| | Effectiveness of hospital response to heat-waves | MCA | Focus group with stakeholders for evaluating their level of satisfaction |
| Economic impact | Cost saving due to saved lives | CBA | Multi-scenario development based on changed |

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|---|---|---|---|
| | | | effectiveness of warning system and hospital response to heat waves. For the economic value of saved lives, we will refer to the Value of Statistical Life (VSL) |
| | Cost saving for the public sector due to average required medical assistance | CBA | Secondary data analysis |
| Impact on policies | Impact on health policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on social service policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on housing policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on public transport policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impacts on urban planning policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| Social impact | Reduced inequalities | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |

*Table 4 - Areas of impacts, methods, and data of socioeconomic impact assessment for Climate and Health.*

## 5.2. Climate and Building Energy

The provided climate service for Building Energy is expected to deliver significant economic impacts. In particularly, an improvement of energy efficiency into private buildings is expected, leading in turn to both a better use of energy and an improved work productivity for indoor workers (e.g. office workers). In the latter case, indoor workers can indeed benefit of a better thermal comfort in their working hours, potentially leading to a more comfortable indoor environment to perform routine work. Impacts are also expected in terms of policies, particularly touching upon the housing policies and associate dimensions such as building construction standards, the use of material, or the building shape. Impacts on policies will also involve the whole built environment, as intervening on individual or multiple buildings will also lead to interact with the environment surrounding buildings. These policies would be key towards the improvement of the urban form. As aforementioned, the provided service will increase the energy efficiency and improve the indoor thermal comfort of buildings, therefore leading to obtain a GHG emission abatement. All these impacts will improve health for householders and indoor workers.

Economic benefits of the provided service can be assessed through CBA or RoI, for example when assessing the cost saving for householders in terms of energy efficiency. Similarly, CBA or RoI can be used in the case of GHG emissions abatement for investigating the cost saving for avoided GHG emissions and mitigation costs. Given an expected improvement into thermal comfort and in turn on work productivity, CBA or RoI will be used for assessing the increased work productivity for those companies adopting more energy efficient solutions. In addition, the impacts by the provided service on a range of policies can be assessed through MCA, that will be continuously supported by the involvement of key stakeholders. Finally, the service is expected to achieve positive effects on citizens' wellbeing and quality of life, therefore the level of satisfaction of householders and indoor workers to the new thermal conditions will be assessed through MCA.

| **Areas of impact** | **Sub-dimension** | **Method to be applied** | **Data gathering process** |
|---|---|---|---|
| Economic impact | Cost saving due to energy efficiency for householders | CBA, RoI | Secondary economic and statistical data analysis |
| | Cost saving due to avoided GHG emissions in terms of public health costs and mitigation costs | CBA, RoI | Secondary economic and statistical data analysis |
| | Increased work productivity for companies adopting more energy efficient solutions | CBA, RoI | Secondary economic and statistical data analysis |
| Impact on policies | Impact on housing policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impacts on built environment policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |

| | | | |
|---|---|---|---|
| Social impact | Reduced inequalities (e.g., reduced disparities among neighbourhoods) at social level | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on wellbeing of householders and workers | MCA | Focus group with stakeholders with scenarios of adoption of new building efficiency solutions |

*Table 5 - Areas of impacts, methods, and data of socioeconomic impact assessment for Building Energy.*

## 5.3. Climate and Urban Planning

The provided service for Urban Planning is expected to deliver significant economic impacts. These will include improvements into the economic values of places and green areas, and a related improved service provision for citizens and investors (e.g. shops, retails, etc..). Cost saving are also expected for health and mitigation costs due to GHG emission abatement, as well as for energy consumption reduction due to the expected cooling effects by vegetation and green spaces. These expected impacts will greatly improve the attractiveness of the city for the investors. The service is also expected to deliver impacts on the public service, such as an increased attention for environmental and climate change-related issues into the Municipality's operations and policies. It would also contribute towards the development and implementation of more sustainable institutional policies and practices. In addition, the service is expected to improve the coordination of the Municipality with external stakeholders which are involved into urban planning issues. This would lead towards an improved working routine into Municipality. Further impacts are expected in terms of quality of life. As aforementioned, the service would increase the number and the quality of public green areas, providing in turn healthier recreation or leisure space for citizens due to their cooling effects. All these expected improvements can largely contribute to increasing the city attractiveness not just from an investors' perspective but also from a citizens' point of view.

Similarly to the previous demonstration case of Building Energy, CBA will be employed to conduct impact assessment for the expected cost saving in terms of energy efficiency, GHG emissions reduction, and mitigation costs. Meanwhile, MCS will be employed for the assessment of expected impacts both on policies and on wellbeing and quality of life for citizens and stakeholders.

| **Areas of impact** | **Sub-dimension** | **Method to be applied** | **Data gathering process** |
|---|---|---|---|
| Impact on public service efficiency and effectiveness | Effectiveness of daily working routine | MCA | Ex-ante: secondary data analysis. Ex-post: interviews to key stakeholders or focus groups |
| Economic impact | Cost saving due to energy efficiency | CBA | Secondary economic and statistical data analysis |

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| | Cost saving due to avoided GHG emissions in terms of public health costs and mitigation costs | CBA | Secondary economic and statistical data analysis |
| Impact on policies | Impact on urban planning policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impacts on health policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impacts on environmental policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| Social impact | Reduced inequalities (e.g., reduced disparities among neighbourhoods) at social level | MCA | Focus group with citizens for evaluating their level of satisfaction + analysis of ex-ante and ex-post interviews of key actors |
| | Impact on quality of life of citizens and commuters | MCA | Focus group with citizens for evaluating their level of satisfaction + analysis of ex-ante and ex-post interviews of key actors |

*Table 6 - Areas of impacts, methods, and data of socioeconomic impact assessment for Urban Planning.*

### 5.4. Climate and Active Mobility

The provided service for Active Mobility is expected to have significant impacts on public services. Improvements are expected in terms of an increase into bike use rate and in the availability of bike paths. Further connected key improvements are expected into traffic management and parking space provision. In this way, the whole urban mobility sector will be increasingly managed in an effective way. Impacts on citizens' wellbeing are also expected, as bike use should lead towards an increased physical activity of citizens. Meanwhile, this would imply that costs for health (as well as for mitigation) will be saved due to GHG emissions abatement, in turn contributing to improve the quality of life of both citizens and commuters. The provided service is also expected to deliver improvements into a vast range of policies, including transport, health and environmental policies.

Given that the provided service is expected to lead to a higher usage of bikes, costs and benefits of bike rate change need to be assessed by using CBA methods. In addition, saving for individuals using the bike are also expected in terms of costs for commuting or transportation, and will be assessed through CBA. MCA methods will be utilized for exploring impacts on policies, such as transport, health and environment. Meanwhile, MCA will be performed to investigate the expected social impacts on wellbeing of citizens and commuters and reduced inequalities for neighbourhoods with poor public transport or transport infrastructure.

| **Areas of impact** | **Sub-dimension** | **Method to be applied** | **Data gathering process** |
|---|---|---|---|
| Impact on public service efficiency and effectiveness | Impact on mobility services (cycle paths) and related investments | RoI | Secondary economic and statistical data analysis |
| | Cost saving due to avoided GHG emissions | CBA | Secondary economic and statistical data analysis |
| | Cost saving for public administration in terms of health cost reductions, mitigation costs, asset management | CBA | Secondary economic and statistical data analysis |
| | Cost saving for individuals using the bike | CBA | Secondary economic and statistical data analysis |
| Impact on policies | Impact on transport policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on other policies such as health and environmental policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| Social impact | Reduced inequalities | MCA | Focus group with citizens for evaluating their level of satisfaction + analysis of ex-ante and ex-post interviews of key actors |
| | Quality of life – wellbeing (in terms of better commuting management time, better work-life balance, etc.) | MCA | Focus group with citizens for evaluating their level of satisfaction + analysis of ex-ante and ex-post interviews of key actors |

*Table 7 - Areas of impacts, methods, and data of socioeconomic impact assessment for Active Mobility.*

## 5.5. Climate and Emergency Planning

The provided service for Emergency Planning is expected to deliver high impacts on public service. Accordingly, cost saving is expected due to a reduction of loss and damage of public assets. Similarly, the management of key services' systems to be monitored in case of floods such as traffic and water is also expected to be improved. In turn, this will lead towards an improvement of emergency planning. The service is also expected to deliver economic benefits. On this regard, improvements would be obtained in terms of cost saving due to reduced loss and damage for business (workers, properties, machinery, products) and business continuity planning. Improvements are also expected for citizens' wellbeing. Indeed, this service would increase the protection of those groups which are more vulnerable to floods and it would increase citizens' awareness about floods and related risks. Finally, the service should touch upon health policies and environmental policies (e.g. land use, management of areas at risk), as well as on disaster risk reduction policies specific for floods. Impacts on citizens' wellbeing and on policies would contribute to improve the overall quality of life.

The expected impacts in terms of effectiveness of emergency planning will be assessed through MCA methods, also by involving institutional stakeholders. The expected cost saving in terms of business continuity, saved lives, and disaster risk reduction measures will be assessed through CBA or RoI according to data availability. Those impacts which are expected on both policies and citizens' wellbeing (e.g., reduced inequalities and improvement in emergency planning in most marginalized communities) will be assessed through MCA.

| **Areas of impact** | **Sub-dimension** | **Method to be applied** | **Data gathering process** |
|---|---|---|---|
| Impact on public service efficiency and effectiveness | Effectiveness of emergency planning | MCA | Ex-ante: analysis of current emergency planning practices. Ex-post: Focus groups with institutional stakeholders |
| | Effectiveness of traffic management | MCA | Ex-ante: analysis of current emergency planning practices. Ex-post: Focus groups with institutional stakeholders |
| Economic impact | Cost saving in terms of business continuity | CBA/RoI | Secondary economic and statistical data analysis |
| | Cost saving in terms of saved lives | CBA | Secondary economic and statistical data analysis |
| | Cost saving due to the implementation of the disaster risk reduction measures | CBA | Secondary economic and statistical data analysis |

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|---|---|---|---|
| Impact on policies | Impact on disaster risk reduction policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on health policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| | Impact on environmental policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development |
| Social impact | Wellbeing, quality of life with attention to current social inequalities | MCA | Focus group with citizens for evaluating their level of satisfaction + analysis of ex-ante and ex-post interviews of key actors |

*Table 8 - Areas of impacts, methods, and data of socioeconomic impact assessment for Emergency Planning.*

### 5.6. Climate and Cultural Heritage

The provided service for Cultural Heritage is expected to lead to a variety of impacts. A significant area of impacts is related to public service. Improvements are indeed expected for the internal governance of SSBAR (for example in terms of efficiency and capacity building), as well as for investments into cultural heritage and measures for wellbeing and health into heritage sites. In turn, this would lead towards a better cultural heritage management. Impacts are also expected in the connected area of tourism sector. In this case, improvements should be obtained in terms of tourism flow management and tourists' health and satisfaction. Further improvements are also expected in terms of provision for a better market position for the tourism sector and of increasing the city attractiveness. Finally, impacts are expected on sectorial policies for tourism and cultural heritage, as well as into environmental policies at large. These impacts would all contribute to improve the management of the key sectors of tourism and cultural heritage.

Impacts on the public service will be assessed through MCA, while the economic impacts will be performed by using CBA and MCA. Impacts on policies (e.g., tourism, cultural heritage, and environmental policies) will be assessed with MCA methods. Experiences and perspectives by tourists will be also considered in order to obtain a larger perspective of the impacts by understanding the point of view of those who will benefit of the urban service. In this way, tourists' wellbeing and satisfaction in terms of e.g. fruition of cultural heritage, protection from weather events, or information on site logistics and necessary equipment and logistics will be assessed through MCA and WTP.

| **Areas of impact** | **Sub-dimension** | **Method to be applied** | **Data gathering process** |
|---|---|---|---|
| Impact on public service efficiency and effectiveness | Tourism flow management | MCA | Ex-ante: analysis of current tourism management practices Ex-post: Focus group/interviews of key stakeholders |
| | Cultural heritage governance | MCA | Ex-ante: analysis of current tourism management practices Ex-post: Focus group/interview of key stakeholders |
| Economic impact | More efficient management of investments for monuments' protection measures | CBA | Secondary economic and statistical data analysis |
| | Increased public image of the city and potential increment in tourism | MCA | Focus group/interviews of key stakeholders |
| Impact on policies | Impact on tourism policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development. |
| | Impact on cultural heritage management policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of policies still under development. |
| | Impact on environmental policies | MCA | Analysis of implemented policies or interview/focus groups of key actors in case of |

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| | | | |
|---|---|---|---|
| | | | policies still under development. |
| Social impact | Tourist wellbeing and satisfaction, including health-related aspects | MCA and WTP | Survey with tourists (online survey) and/or sentiment analysis on social media |

*Table 9 - Areas of impacts, methods, and data of socioeconomic impact assessment for Cultural Heritage.*

### 5.7. From impacts to exploitability

Tables 4-9 have described the most significant areas of socioeconomic impacts, related subdimensions, and the potential methods to be applied for their assessment. These methods, particularly but not limited to MCA, could be further complemented by the WTP method (see Section 4.2). Indeed, WTP would allow further refining the socioeconomic impact assessment by understanding the willingness by stakeholders and end-users to pay for e.g. improving, updating or customizing the provided climate service. This further refinement potentially provided by the WTP would serve to complement economic impact assessment to be used as a baseline for exploitability of the provided climate service. This would be also useful as an input for the future activities of WP7, that aims at designing and implementing targeted marketing strategies for end-users, purveyors and urban climate data providers.

## 6. Conclusions

Climate-fit.city gathers diverse expertise for the development and application of project's activities. These activities are complex and innovative for a variety of urban contexts and will touch upon different social and economic aspects. Impacts by these activities therefore need to be assessed through an appropriate methodological approach and related set of data gathering and data analysis techniques which will rely on experiences from pre-existing research projects. The methodological approach will be weighted on the characteristics of each addressed climate service in order to identify the most peculiar aspects of each one. Towards this goal, the present deliverable has initially identified the main impacts by climate change on each sector addressed by the specific urban services. It has then described a set of selected methodologies to be employed in the project for conducting socioeconomic impact assessment. After, it has presented main areas of impacts by each provided service and related subdimensions, selected methodology for the assessment and data gathering and analysis approaches for conducting such assessment. Based on the background provided by this deliverable, future steps of the WP6 include providing a zero scenario for each demonstration case in order to have a portrait of the initial condition (this will be the core objective of D6.2). From this, the refinement of the methodology for the socioeconomic impact assessment here presented will continue in the following WP6's activities following the project activities and welcoming eventual need for fine-tuning.

The involvement of both project's partners and stakeholders of each climate service has been an outstanding added value for the finalization of this deliverable and will be key as well for the future development, refinement and application of the socioeconomic impact assessment methodology. Therefore, the deliverable truly resulted as a collaborative and coordinated effort among the project partners and between project partners and stakeholders.

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