# AdriaClim

## Climate change information, monitoring and management tools for adaptation strategies in Adriatic coastal areas

Project ID: 10252001

# **D.5.4.7** Guidelines to support cities in developing adaptation plans for Veneto project area

## PP02 – ARPAV

Final version

Public document

June, 2023

Month, Year

| | |
|---|---|
| Project Acronym: | AdriaClim |
| Project ID Number: | 10252001 |
| | Prject Title: Climate change information, monitoring and management tools for adaptation strategies in Adriatic coastal areas |
| Priority Axis: | 2 - Climate change adaptation |
| Specific objective: | 2.1 - Improve the climate change monitoring and planning of adaptation measures tackling specific effects, in the cooperation area |
| Work Package Number: | 5 |
| Work Package Title: | Adaptation Plans |
| Activity Number: | 5.4 |
| Activity Title: | Veneto Coastal Pilot: Adaptation/Mitigation/Intervention Plan |
| Partner in Charge: | P02 ARPA Veneto |
| Partners involved: | P01 CNR, P09 CMCC, P14 AULSS3, P17 COV |
| Status: | Final |
| Distribution: | Public |
| Date: | 30/06/2023 |

| | |
|---|---|
| **Work Package:** | 5. Adaptation plans |
| **Activity:** | 5.4 Veneto coastal pilot: adaptation/mitigation/intervention plan |
| **Deliverable:** | D.5.4.7 Guidelines to support cities in developing adaptation plans for Veneto project area |
| Authors | ARPA Veneto: Francesco Rech, Giovanni Massaro, Fabio Zecchini;<br>IUAV: Francesco Musco, Denis Maragno, Filippo Magni, Gianfranco Pozzer, Nicola Romanato;<br>CMCC@Ca'Foscari: Silvia Torresan, Maria Katherina Dal Barco, Davide Mauro Ferrario, Ngoc Diep Nguyen, Margherita Maraschini, Heloisa Labella Fonseca, Olinda Rufo, Stefania Gottardo, Andrea Critto. |
| Due month | M42 |
| Delivery month | M42 |

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## Introduction

Two alternatives are available to deal with the impacts of climate change: mitigation and adaptation.

Mitigation seeks to solve the problem 'at the root' by reducing greenhouse gas emissions; thus addressing a global problem with actions that can only be effective if applied on a global scale and persistently over time.

Adaptation has been a common practice for mankind since the dawn of time. When faced with a problem, solutions are sought and at least one must be found because often what is at stake is survival.

The Veneto Region has been shaped by the adaptation measures implemented over the centuries. Are remembered the river embankments, also mentioned by Dante in Canto XV of Inferno, the thousands kilometers of canals and artificial ditches that shape the rural landscape, the work carried out by the Serenissima to divert the great rivers by moving their mouths outside the Venice Lagoon, the terracing in hill and mountain areas, the agricultural reclamation works that have made thousands of square kilometers of land below the mean sea level cultivable through the construction of complex systems of embankments, canals and water drainage systems to lift rainwater. Especially during the last century, this has been increasingly overlaid by a complex network of communication routes, residential and production settlements, and tourist facilities and settlements.

Adaptation interventions, as opposed to mitigation interventions, are often strictly dependent on the specific geomorphologic, infrastructural and socio-economic characteristics of the territorial context where one wants to intervene.

They are therefore actions that must generally be studied, shared, planned and implemented at a local level, making the best use of the entire body of knowledge available to the community.

Compared to the past, the new and worrying element is the speed of change in climate characteristics. It is worth recalling the increase of + 0.57 °C per decade observed over the Veneto Region in the last 30 years.

The pace of climate change that is looming and the real possibility of synergistic effects between different factors, must make planners consider very carefully the effectiveness and efficiency of the adaptation measures they intend to adopt; in fact, in such a scenario, the adaptation actions implemented or planned may become insufficient or too costly, or may even end up worsening certain situations in the long run.

For planning processes, it is therefore important to share knowledge and expertise in order to create a multi-sectoral vision that can more comprehensively consider the complexity of the reality that surrounds us, also taking into account future climate trends.

Furthermore, it is important to ensure maximum openness to the world of knowledge, science and research in order to

- better define the climate scenarios of the future;
- identify innovative solutions in adaptation and mitigation pathways.

The guidelines developed in this deliverable propose to provide public administrators and private operators with tools and operational elements useful for defining work paths aimed at implementing climate change adaptation measures.

## Climate change a global problem in the IPCC's vision

The weather and climatic adversities that affect our area have distant origins in time and space. They are determined by a global change caused, most likely by human activities which have released into the atmosphere, in a hundred years, reserves of carbon dioxide accumulated over millions of years.

To have a global view of the Climate Change problem it is advisable to analyze the periodic reports of the IPCC. The IPCC (Intergovernmental Panel on Climate Change) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). It was recognized the same year by the United Nations General Assembly. Is an international body that reviews and evaluates the latest scientific, technical and socio-economic information from around the world relating to the issue of climate change. This institution does not carry out research or monitoring directly, but collects and organizes studies conducted by researchers from all over the world on the subject of climate and climate change. Periodically this body produces Assessment Reports on the state of the climate on our planet and below is a summary of the contents of the sixth report released in 2022.

### The climate change

Human activities, principally through emissions of greenhouse gasses, have *unequivocally* caused global warming, with global surface temperature reaching 1.1 °C above 1850-1900 in 2011-2020.

Global greenhouse gas emissions have continued to increase over 2010-2019, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and between individuals (*high confidence*).

Human-caused climate change is already affecting many weather and climate extremes in every region across the globe.

This has led to widespread adverse impacts on food and water security, human health and on economies and society and related losses and damages to nature and people (*high confidence*). Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (*high confidence*).

## Observed warming, its causes and effects

Global surface temperature was around 1.1 °C above 1850–1900 in 2011–2020 (1.09°C [0.95°C– 1.20°C]) , with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 °C [0.68 °C– 1.01 °C]) . Observed warming is human-caused, with warming from greenhouse gasses (GHG), dominated by $CO_2$ and methane ($CH_4$), partly masked by aerosol cooling. Global surface temperature in the first two decades of the 21st century (2001-2020) was 0.99 [0.84 to 1.10] °C higher than 1850-1900. Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). The likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–20199 is 0.8 °C to 1.3 °C, with a best estimate of 1.07 °C. It is likely that well-mixed GHGs contributed a warming of 1.0 °C÷2.0 °C, and other human drivers (principally aerosols) contributed a cooling of 0.0 °C÷0.8 °C, natural (solar and volcanic) drivers changed global surface temperature by ±0.1 °C and internal variability changed it by ±0.2 °C.

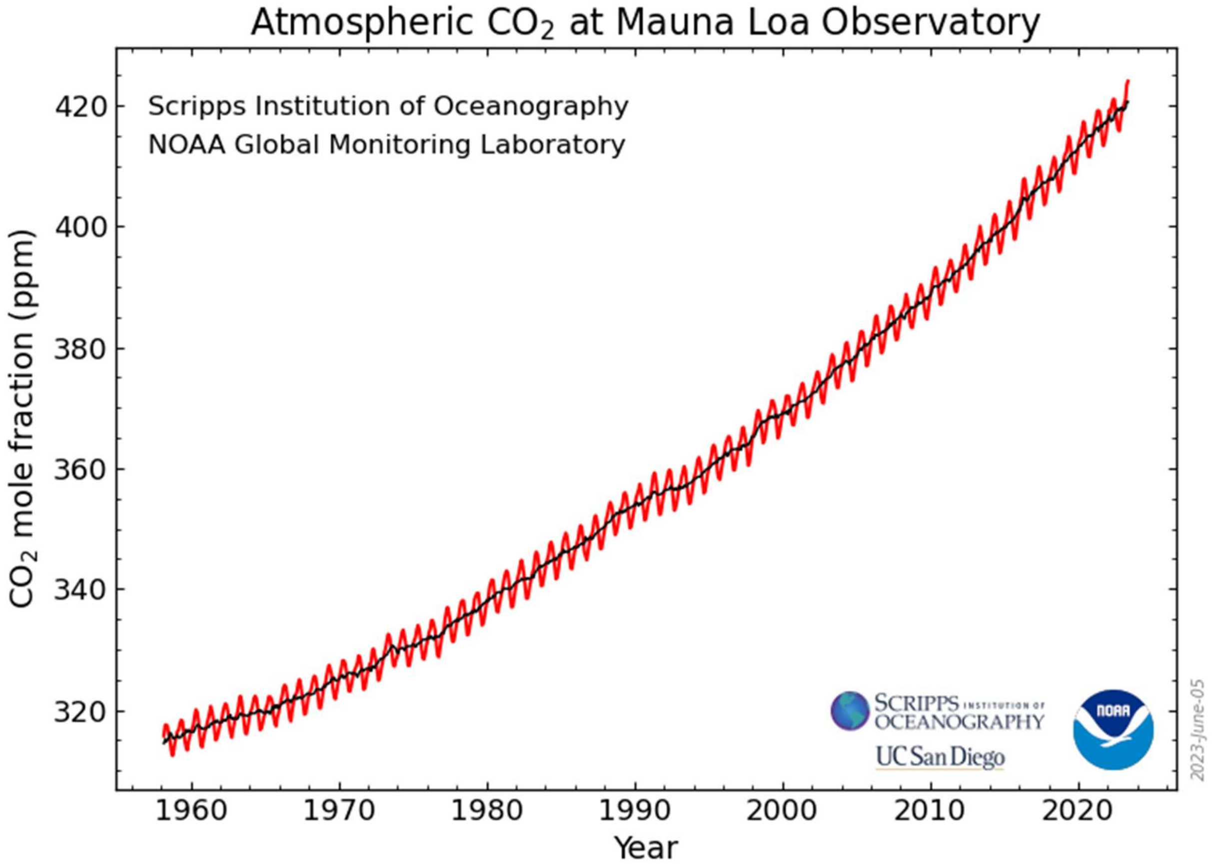

*Figure 1. The graphs show monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii. (https://gml.noaa.gov/ccgg/trends/)*

Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by GHG emissions from human activities. Land and ocean sinks have taken up a near-constant proportion (globally about 56% per year) of $CO_2$ emissions from human activities over the past six decades, with regional differences (*high confidence*). In 2019, atmospheric $CO_2$ concentrations reached 410 parts per million (ppm), $CH_4$ reached 1866 parts per billion (ppb) and nitrous oxide ($N_2O$) reached 332 ppb11. Other major contributors to warming are tropospheric ozone ($O_3$) and halogenated gasses. Concentrations of CH4 and $N_2O$ have increased to levels unprecedented in at least 800,000 years (*very high confidence*), and there is high confidence that current $CO_2$ concentrations are higher than at any time over at least the past two million years. Since 1750, increases in $CO_2$ (47%) and $CH_4$ (156%) concentrations far exceed – and increases in

$N_2O$ (23%) are similar to – the natural multi-millennial changes between glacial and interglacial periods over at least the past 800,000 years (*very high confidence*). The net cooling effect which arises from anthropogenic aerosols peaked in the late 20th century (*high confidence*).

***"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred."***

The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years. It is very likely that GHG emissions were the main driver of tropospheric warming and extremely likely that human-caused stratospheric ozone depletion was the main driver of stratospheric cooling between 1979 and the mid-1990s. It is virtually certain that the global upper ocean (0-700m) has warmed since the 1970s and extremely likely that human influence is the main driver. Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (*high confidence*). Global mean sea level increased by 0.20 [0.15÷0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1]mm yr-1 between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr-1 between 1971 and 2006, and further increasing to 3.7 [3.2 to ÷4.2] mm yr-1 between 2006 and 2018 (*high confidence*). Human influence was very likely the main driver of these increases since at least 1971. Human influence is very likely the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019. Human influence has also very likely contributed to decreased Northern Hemisphere spring snow cover and surface melting of the Greenland ice sheet. It is virtually certain that human-caused $CO_2$ emissions are the main driver of current global acidification of the surface open ocean.

***"Human-caused climate change is already affecting many weather and climate extremes in every region across the globe*."**

Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5. It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with high confidence that human caused climate change is the main driver of these changes. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has very likely contributed to most of them since at least 2006. The frequency and intensity of heavy precipitation events have increased since the 1950s over most land areas for which observational data are sufficient for trend analysis (high confidence), and human-caused climate change is likely the main driver. Human-caused climate change has contributed to increases in agricultural and ecological droughts in some regions due to increased land evapotranspiration (medium confidence). It is likely that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades.

Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater, cryospheric and coastal and open ocean ecosystems (*high confidence*). The extent and magnitude of climate change impacts are larger than estimated in previous assessments (*high confidence*).

Climate change has reduced food security and affected water security due to warming, changing precipitation patterns, reduction and loss of cryospheric elements, and greater frequency and intensity of climatic extremes, thereby hindering efforts to meet Sustainable Development Goals (*high confidence*).

In urban settings, climate change has caused adverse impacts on human health, livelihoods and key infrastructure (*high confidence*). Hot extremes including heatwaves have intensified in cities (*high confidence*), where they have also worsened air pollution events (*medium confidence*) and limited functioning of key infrastructure *(high confidence*). Urban infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). Observed impacts are concentrated amongst economically and socially marginalised urban residents, e.g., those living in informal settlements (*high confidence*). Cities intensify human-caused warming locally (*very high confidence*), while urbanisation also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*).

Climate change has adversely affected human physical health globally and mental health in assessed regions (*very high confidence*), and is contributing to humanitarian crises where climate hazards interact with high vulnerability (*high confidence*). In all regions increases in extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases has increased (*very high confidence*). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (*high confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from extreme events (*very high confidence*), and loss of livelihoods and culture (*high confidence*).

Human influence has likely increased the chance of compound extreme events since the 1950s. Concurrent and repeated climate hazards have occurred in all regions, increasing impacts and risks to health, ecosystems, infrastructure, livelihoods and food (*high confidence*). Compound extreme events include increases in the frequency of concurrent heatwaves and droughts (*high confidence*); fire weather in some regions (*medium confidence*); and compound flooding in some locations (*medium confidence*). Multiple risks interact, generating new sources of vulnerability to climate hazards, and compounding overall risk (*high confidence*). Compound climate hazards can overwhelm adaptive capacity and substantially increase damage (*high confidence*).

## Future climate change

Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5 °C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards (*high confidence*). Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (*high confidence*).

For any given future warming level, many climate-related risks are higher than assessed in AR5, and projected long-term impacts are up to multiple times higher than currently observed (*high confidence*). Risks and projected adverse impacts and related losses and damages from climate change escalate with every increment of global warming (*very high confidence*). Climatic and non-climatic risks will increasingly interact, creating compound and cascading risks that are more complex and difficult to manage (*high confidence*).

Some future changes are unavoidable and/or irreversible but can be limited by deep, rapid and sustained global greenhouse gas emissions reduction. The likelihood of abrupt and/or irreversible changes increases with higher global warming levels. Similarly, the probability of low-likelihood outcomes associated with potentially very large adverse impacts increases with higher global warming levels. (*high confidence*)

Adaptation options that are feasible and effective today will become constrained and less effective with increasing global warming. With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits. Maladaptation can be avoided by flexible, multi-sectoral, inclusive, long-term planning and implementation of adaptation actions, with co-benefits to many sectors and systems. (*high confidence*).

## Urgency of near-term integrated climate action

Climate change is a threat to human well-being and planetary health (*very high confidence*). There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all (*very high confidence*). Climate resilient development integrates adaptation and mitigation to advance sustainable development for all, and is enabled by increased international cooperation including improved access to adequate financial resources, particularly for vulnerable regions, sectors and groups, and inclusive governance and coordinated policies (*high confidence*). The choices and actions implemented in this decade will have impacts now and for thousands of years (*high confidence*).

## Adapting to climate change: implications for impact and vulnerability assessment at local level

In the Mediterranean area, in particular, the conditions that alter the climate balance are more severe, such as the increase in temperature and the decrease in summer rainfall, and the vulnerability is more accentuated with respect to other regions, leading to more serious climatic risk (Giorgi and Lionello, 2008; Ali et al., 2022), originating the latter from the interaction among hazard, vulnerability and exposition.

The Mediterranean region will most likely become hotter and drier; sea level will increase following the global mean increase and it will be progressive on multi-secular scales (Ali et al., 2022).

The scale of all these changes increases as the level of global warming increases, i.e. the more the average temperature of the planet increases, the greater the impacts on the Mediterranean region will be. To limit the impacts and risks deriving from climate change, it is necessary to act on two different but complementary aspects: mitigation (any human intervention that reduces emissions or strengthens the sources of absorption of greenhouse gases) and adaptation (process of adjusting to the current or expected climate and its impacts, in order to limit the damage or take advantage of favorable opportunities).

While global efforts to reduce emissions are essential (mitigation), the impacts of climate change are already ongoing and will continue to have effects in the next decades. Therefore complementary adaptation actions are needed, at national, regional and local level, aimed at limiting the vulnerability of exposed systems and strengthening their resilience, thus preventing or reducing the risks associated with climate change (IPCC, 2022).

### Identification of the hazards

An assessment of climate change and its variability at a regional scale is necessary to support mitigation actions, for the development of adaptation strategies and plans and hence for appropriate territory planning in the several socio-economical regional sectors. Therefore, the quantification of the meteo-climatic ongoing trends as well as the possible future scenarios is essential.

## The climate in Veneto

The discontinuity study carried out on the temperature data of the mechanical stations belonging to the former Hydrographic Office of the Venice Water Authority, covering fifty years from the 1950s to the early 2000s, highlighted a breaking point around the end of the 1980s which separates a first period of practically stable temperatures, and a second period of gradual temperature increase. The temperature data from the Arpav automatic stations, which have accompanied and replaced the data from the mechanical stations since the 1990s, confirm the upward trend.

In Veneto the trend of increase in the average annual temperature detected by the Arpav regional meteorological station network for the period 1993-2022, roughly homogeneous throughout the region, is on average + 0.57 °C per decade (Figure 2-3) and is statistically significant for almost all of the different areas of the territory. For comparison, the global growth trend for land surface estimated by NOAA (National Oceanic and Atmospheric Administration, USA) for the same period is equal to + 0.38 °C per decade. The average annual temperatures in 2022 in Veneto were the highest in at least thirty years.

Other temperature-related indicators also highlight the change taking place. For example, there is an increase in the number of tropical nights, defined as days with a minimum temperature > 20 °C, and summer days with a maximum temperature above 30 °C (Figure 4). There is then a specular decrease in frost days.

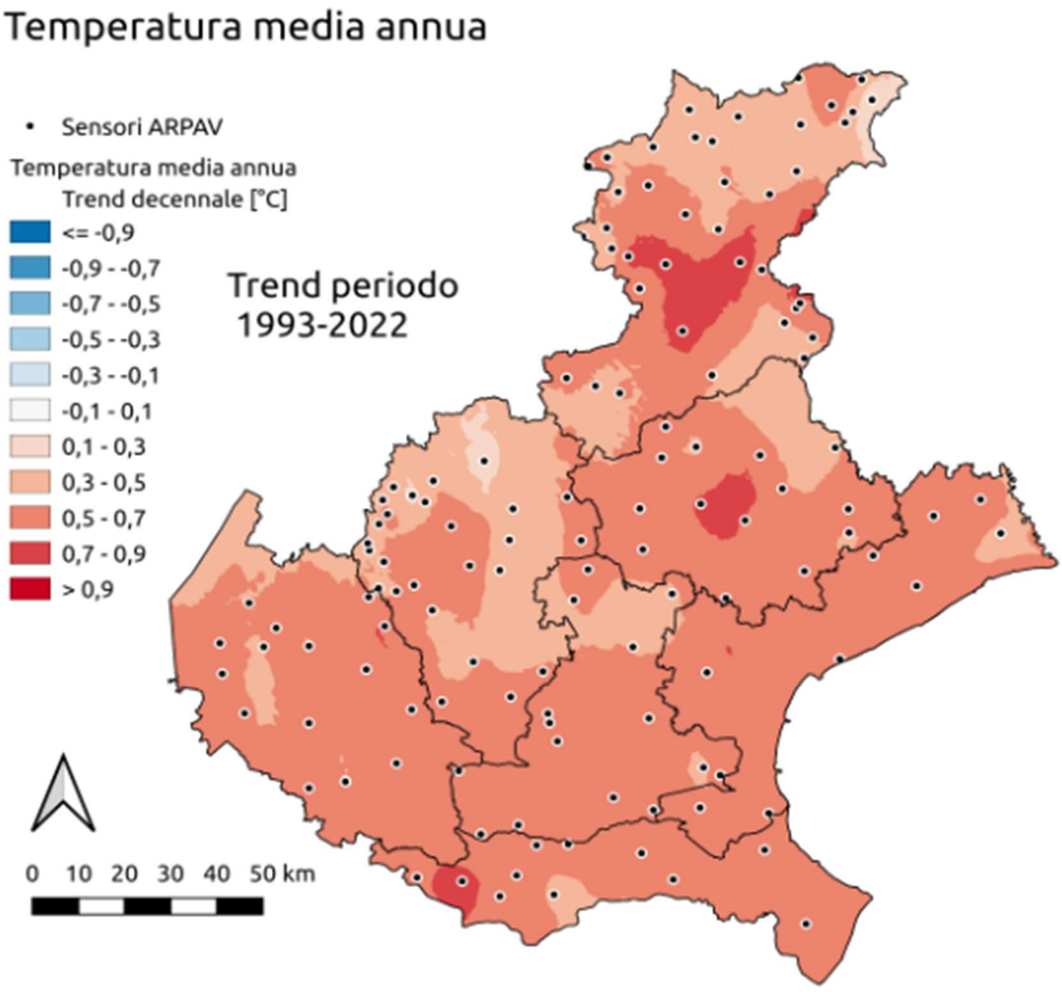

*Figure 2. 10-year trend of the annual mean temperature in Veneto, estimated from 1993 to 2022.*

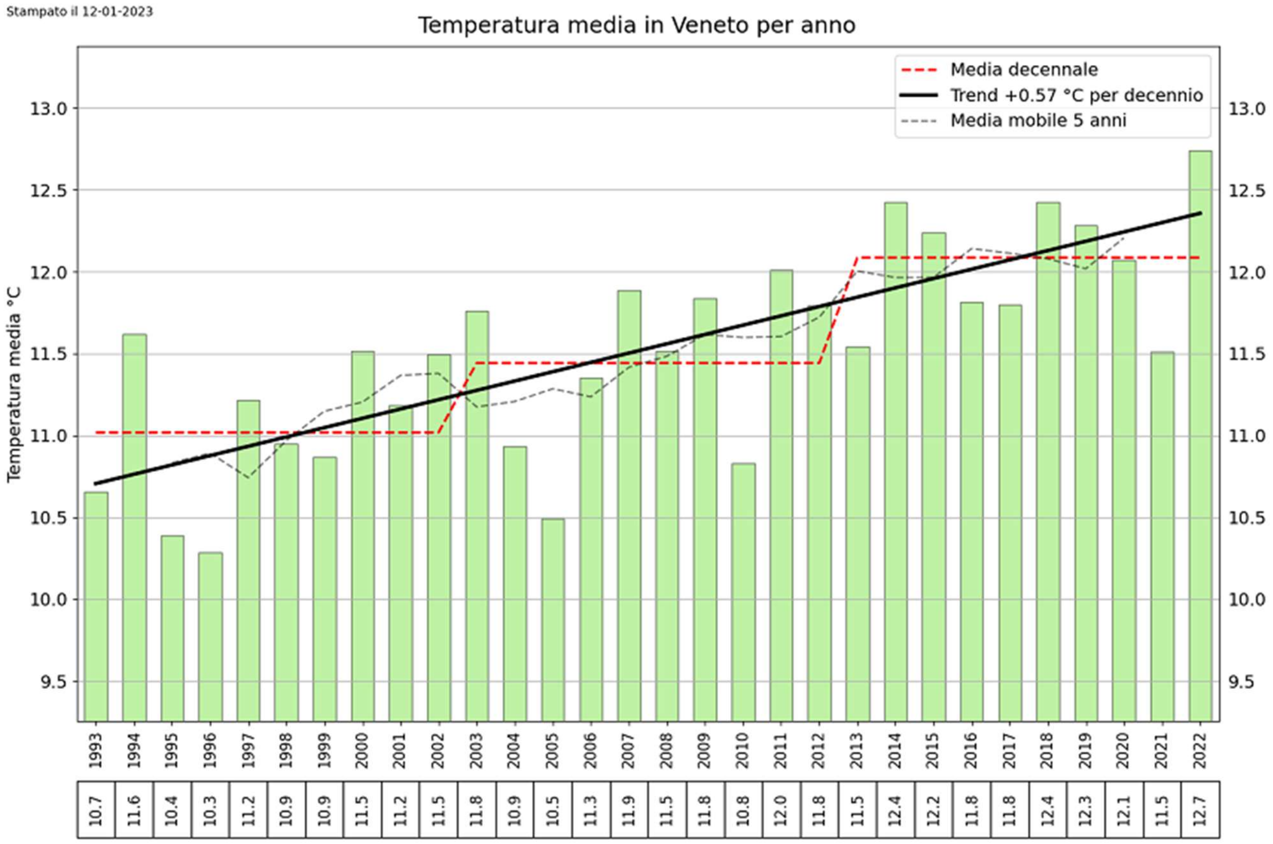

*Figure 3. Annual mean temperature in Veneto from 1993 to 2022. The bold black line represents the trend, the dotted line is the 5-year moving average, the red one is the 10-year mean.*

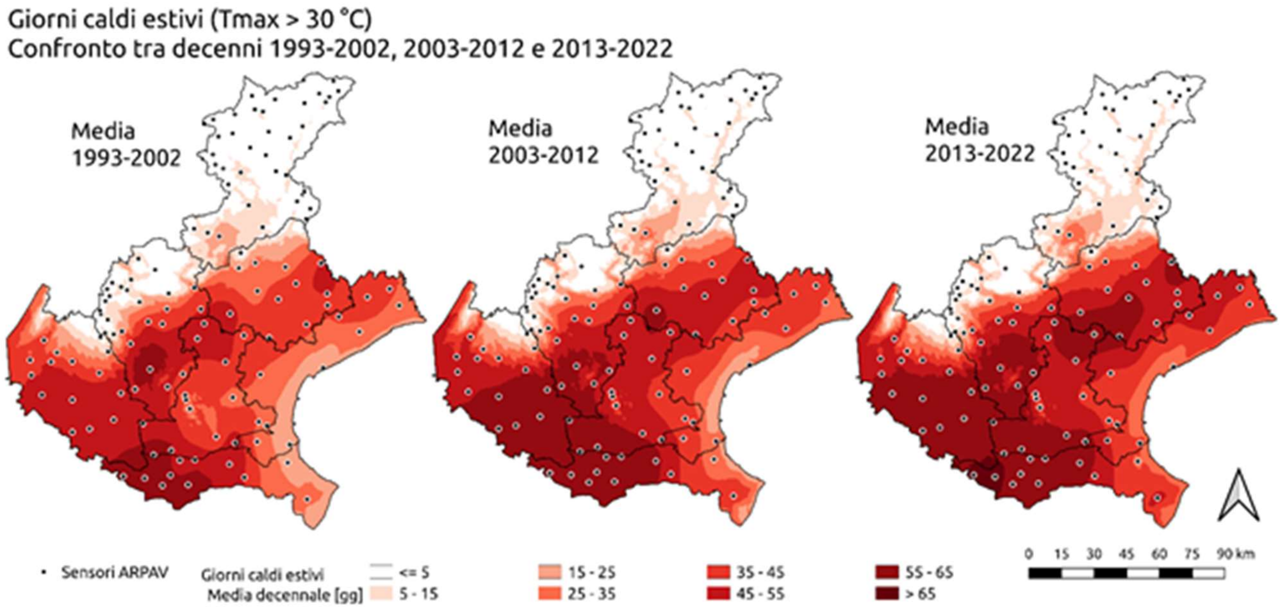

*Figure 4. Comparison of the number of summer days over the past three decades. The 30°C threshold of daily maximum temperatures was used to determine summer days.*

Moving from temperature to precipitation, no statistically significant trends were found for the latter (Figure 5). The cumulative precipitation, averaged on a regional scale, both at an annual and at a seasonal level, has not recorded any significant changes in the last thirty years. Even by extending the analysis to the second half of the last century, thanks to the data from the mechanical stations from the former Hydrographic Office, it is not possible to identify significant trends. On the other hand, a marked inter-annual variability appears which is shown in the graphs, together with the cumulative precipitation, represented by the standard deviation evaluated over a mobile decade. The latter is increasing with a statistically significant trend both annually and for the winter, spring and summer meteorological seasons, whereas for autumn it is decreasing with a statistically significant trend.

As regards the annual rainfall in 2022, an absolute minimum has been observed since 1951. Our region suffered a rainfall deficit which lasted from February 2021 to April 2023; out of 27 months 6 had overall rainfall above the average, 2 months average rainfall while the remaining 19 months had variable rainfall deficits between -20% and -96% of the thirty-year average monthly rainfall, on the contrary May 2023 was very rainy and in particular in the southern basins of Veneto it turned out to be the wettest May of the last thirty years.

Although there are no statistically significant trends in rainfall, looking at heavy rainfall it is possible, in certain cases, to detect a sign of increase, particularly in the last two decades when compared to the previous one (Figure 6).

Other climate indicators for Veneto Region can be found in the climate change section on the ARPA Veneto institutional website at the following link:

https://www.arpa.veneto.it/temi-ambientali/cambiamenti-climatici/atlante-climatico-1

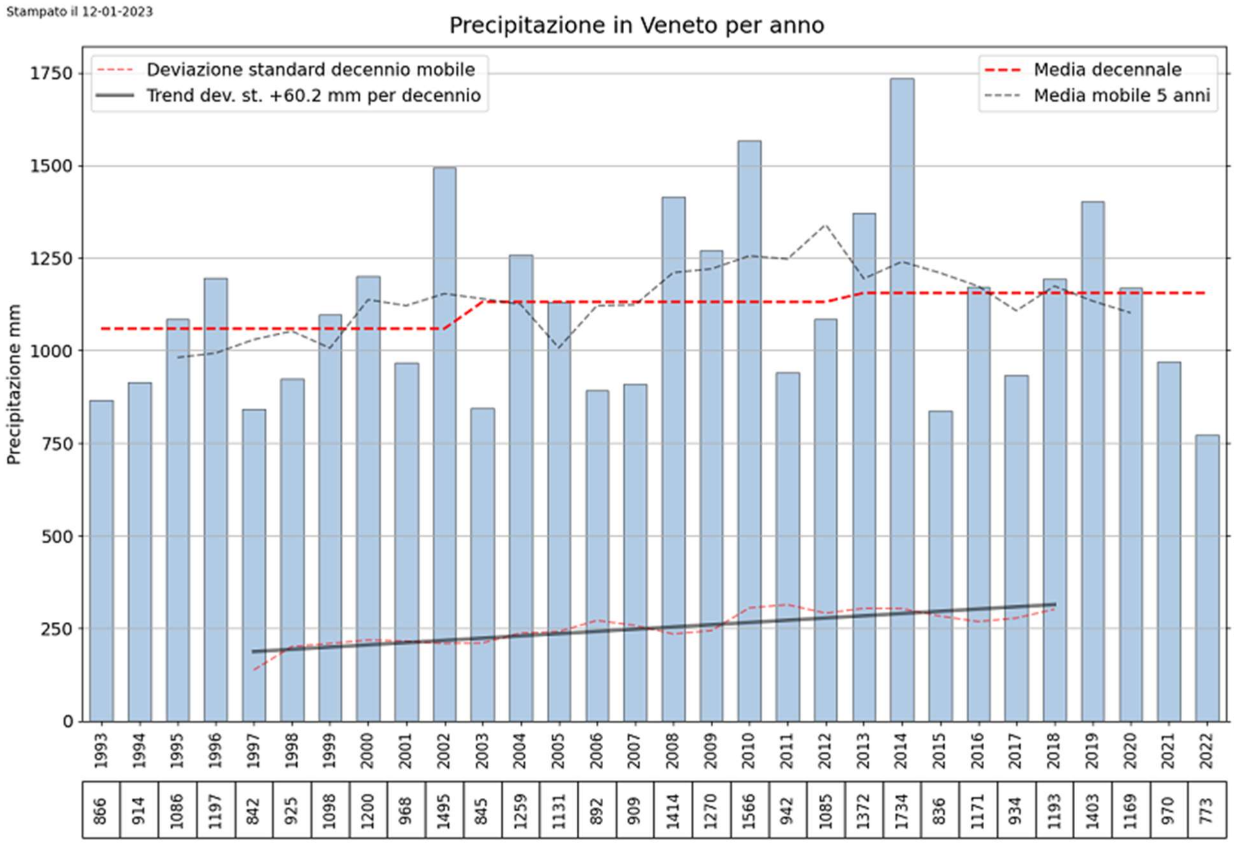

*Figure 5. Annual mean cumulative precipitation in Veneto from 1993 to 2022. The bold black line represents the trend, the dotted line is the 5-year moving average, the bold red line is the 10-year mean and the red dotted one the standard deviation 10-year moving average.*

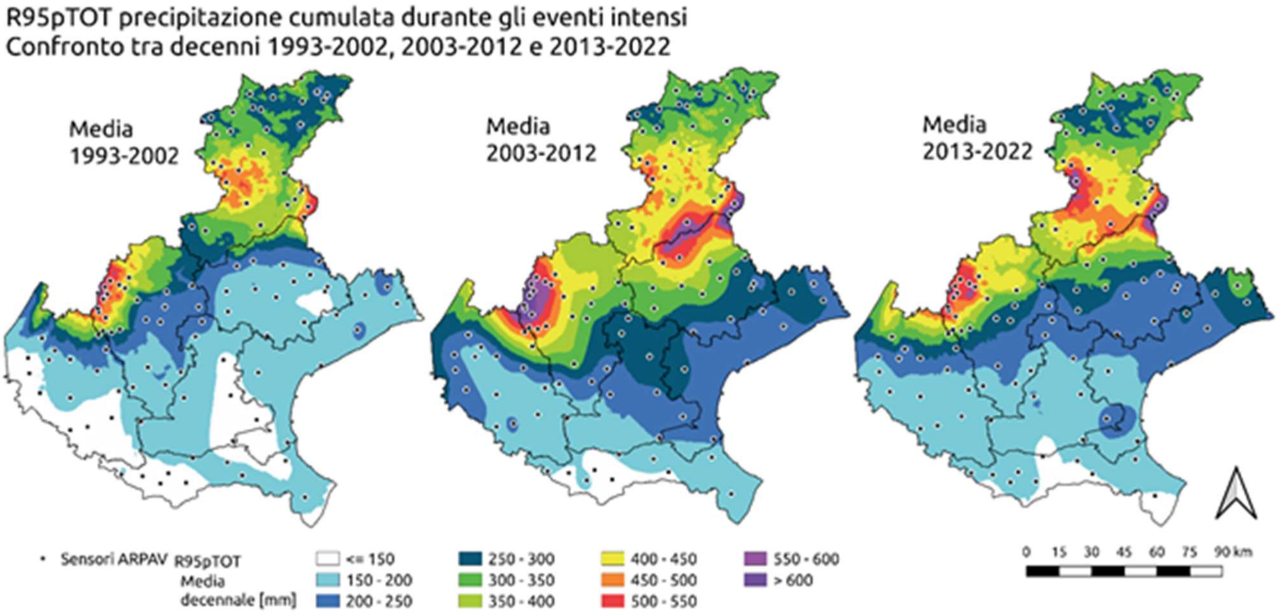

*Figure 6. Comparison of cumulative annual precipitation during intense events over the last three decades. A heavy rainfall is defined as such if the daily quantity exceeds the quantity corresponding to the ninety-fifth percentile, evaluated over the normal period 1991-2020.*

Among the extreme events that have produced the most damage, we mentioned:

- September 26th 2007: flooding in Mestre;
- 31 October-2 November 2010: flood in Veneto;
- 30 January-4 February 2014: record snowfall in the dolomites, flooding rivers in the north-east Veneto;
- 8 July 2015: Dolo's tornado with destruction of a Venetian Villa (Villa Fini);
- 10 August 2017: downbursts on Albarella (RO) and on Veneto coast (serious damage to coastal pine forest and tourist facilities);
- 27-30 October 2018: Vaia storm;
- 12 November 2019: exceptional tide in Venice (187 cm), never so high since 1966 (194 cm);
- 22 November 2022: storm surge in the northern Adriatic with much damage. MOSE spares Venice an exceptional tide (173 cm).

As regards Vaia storm (October 27-30, 2018) it is interesting to recall how, in the days preceding the event, due to the prolonged presence of a situation with high temperatures and low rainfall and due to the presence of Föhn phenomena, there was on the Veneto mountain an emergency situation for important forest fires. During the event, significant rainfall was recorded in the mountain sector (with a fall of 716 mm in three days at Soffranco BL) which produced multiple phenomena of hydrological instability in the mountain sector and flooding in the floodplain areas of the rivers in the Veneto Plains. Furthermore, in the final phase of the event the wind significantly strengthened causing important crashes of forest plants on the whole mountain sector. There are about 12,227 hectares of forest cut down in Veneto and 42,500 hectares cut down overall in the Alps (Estimate of the damage of the storm "Vaia" to forests in Italy, 2019, Chirici, Gherardo et alii, Rivista di Selvicoltura ed Ecologia Forestale. 16. 3- 9. 10.3832/efor3070-016) (Figure 7). During this event there were also important phenomena of high tide in Venice and storm surges on the coast.

*Figure 7. Plants blown down by the wind in Val Visdende BL (source: Veneto Region).*

Climate change therefore manifests itself in our regional territory both with an increase in the frequency of occurrence of extreme phenomena and with an increase in the intensity of atmospheric phenomena.

## Climate projections in the North-Est Italy

In order to understand the possible impacts of climate change at the local scale for the future decades, the state-of-the-art regional climate projections (EURO-CORDEX 0.11 degs; http://www.euro-cordex.net/) have been acquired and adapted to the Veneto territory by using a bias correction method (linear scaling) in addition to the regional meteorological station network from Arpav and Arpa FVG.

An ensemble of 5 regional climate models have been selected and three different Representative Concentration Pathways (RCPs) have been considered:

- RCP2.6: scenario with strong mitigation of greenhouses, corresponds to an atmospheric CO2 concentration by 2100 similar to the current one (about 420 ppm) and aims to keep the global warming below 2°C with respect to the pre-industrial values;
- RCP4.5: intermediate scenario of stabilization, the CO2 concentration stabilizes around 538 ppm by 2100;
- RCP8.5: scenario with no mitigation or business-as-usual, with a CO2 concentration by 2100 larger than 900 ppm.

The results show the strong difference between the low emission scenario RCP2.6 and the high emission scenario RCP8.5 for the climate change in North-East Italy.

In the first case, the change in temperature and precipitation tends to stop in the second part of the 21st century.

In the second case the change continues throughout the century with substantial warming (+5°C in summer, +4°C in winter); it is expected an increase in precipitation in winter (up to +25% in the alpine sector) and a decrease in summer (up to -30% in the plains) in the far future. Warming is greater in mountain and alpine areas than in coastal and flat areas. In the mountain areas there is also an increase in the intense precipitation (total cumulative precipitation above the 95th percentile of the reference period) in winter (up to +80%) for the RCP8.5 scenario and the period 2071-2100. For the same period and scenario, in the coastal areas there is a substantial increase of summer days (number of days with a maximum temperature above 30°C) (up to +60 days).

The study has considered seasonal anomalies, variations of the expected value in the future with respect to the reference period, for temperature, precipitation, summer days and intense precipitation. Three 30-year periods were selected: a reference period (from 1976 to 2005), near future (2021-2050) and far future (2071-2100).

The time series of the annual temperature anomaly up to 2100 with respect to the reference period 1976-2005 for the ensemble mean of the RCP2.6 and RCP8.5 scenarios for the summer is shown in Figure 8: the anomaly at 2100 rises, respectively, from 1.5°C to 5.5°C.

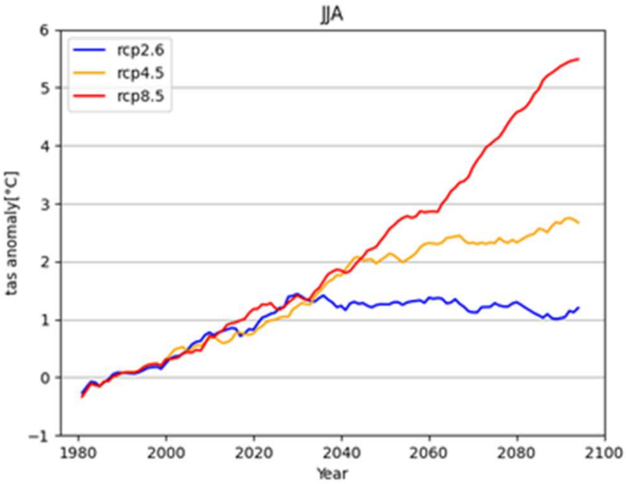

*Figure 8 - Annual temperature anomaly with respect to the reference period 1976-2005 for the 3 RCPs in summer. Values are averaged over all the considered spatial domain (North-East italy) and represent the ensemble mean and cover the period from 1976 to 2100. A 11-year moving average has been applied to each timeseries. RCP refers to Representative Concentration Pathways.*

The geographical distribution of the ensemble mean of the temperature anomaly is shown in Figure 9 for the period 2071-2100 and winter. Crosses in the map indicate grid points where agreement between models is low, i.e. the ensemble mean is less than the standard deviation between models. For all scenarios the models are statistically in agreement over almost the entire domain. Warming is between 1°C and 1.5°C moving from flat to alpine areas for RCP2.6, and increases from 3.5°C in flat areas to 5°C in alpine areas for RCP8.5.

If precipitation is considered, only the 30-year period 2071-2100 with RCP8.5 has good agreement between models. The geographical distribution of the precipitation anomaly is shown in Figure 10 for winter and Figure 11 for summer, considering the 2071-2100 period and RCP2.6/RCP8.5. By considering the RCP8.5 in winter, the precipitation anomaly is positive, greater for the Alpine area than for the flat areas (from +15% to +35% against values between +10% and +20%, respectively); in summer the anomaly is negative, with a maximum of -30% in the flat areas.

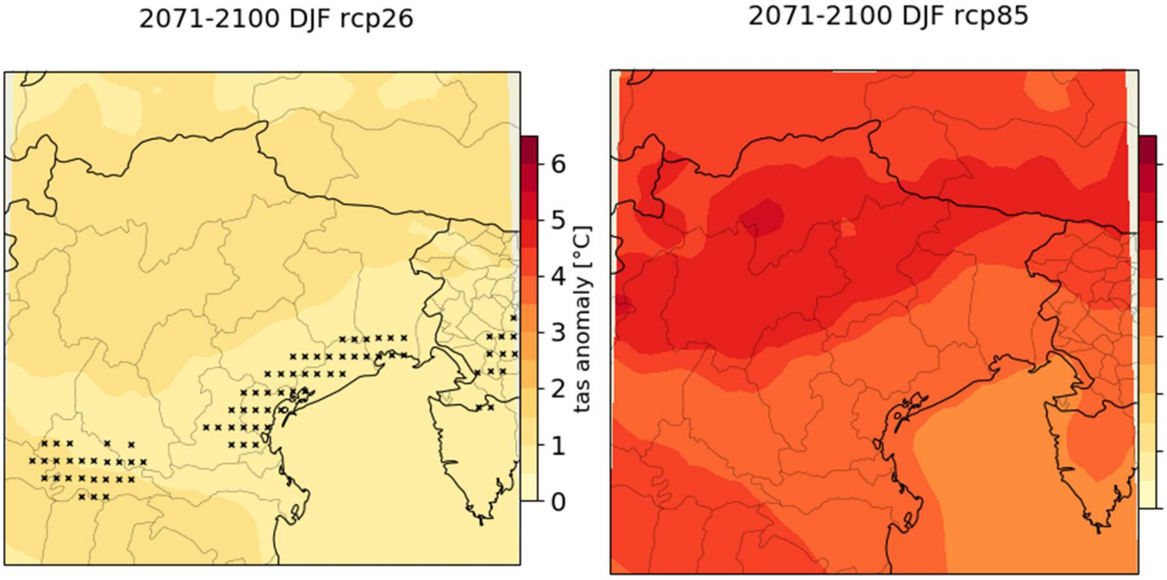

*Figure 9. Geographical distribution of the temperature anomaly in winter for the 2071-2050 with respect to the reference period 1976-2005; the left/right hand side refer to RCP2.6/RCP8.5. Crosses indicate the grid points where the models agreement is low.*

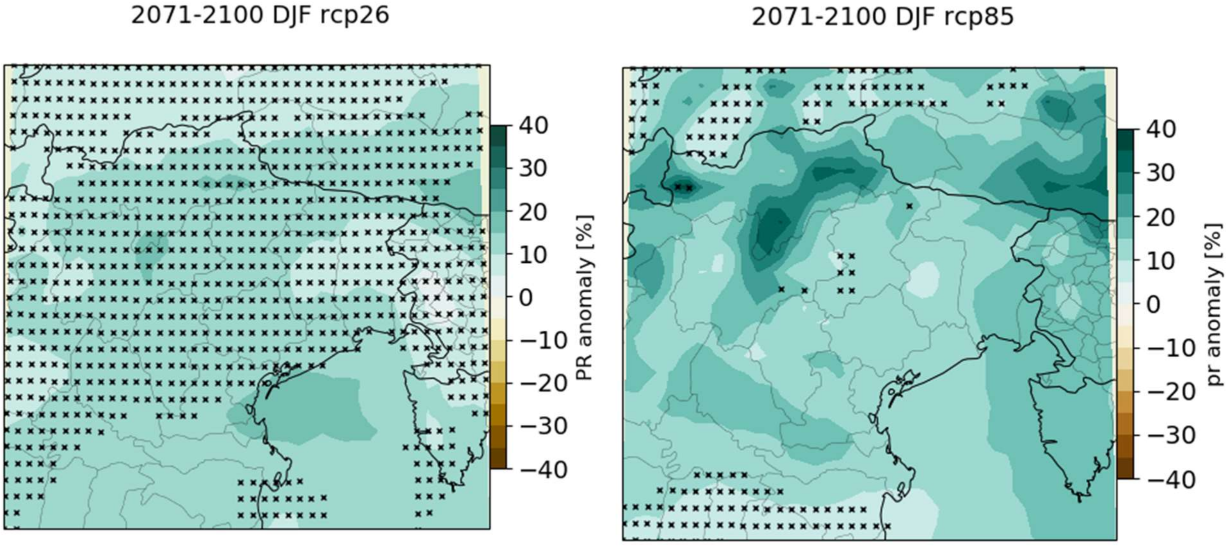

*Figure 10. Geographical distribution of the precipitation anomaly (units: percent of baseline value) in winter for the 2071-2100 with respect to the reference period 1976-2005; the left/right hand side refer to RCP2.6/RCP8.5. Crosses indicate the grid points where the model agreement is low.*

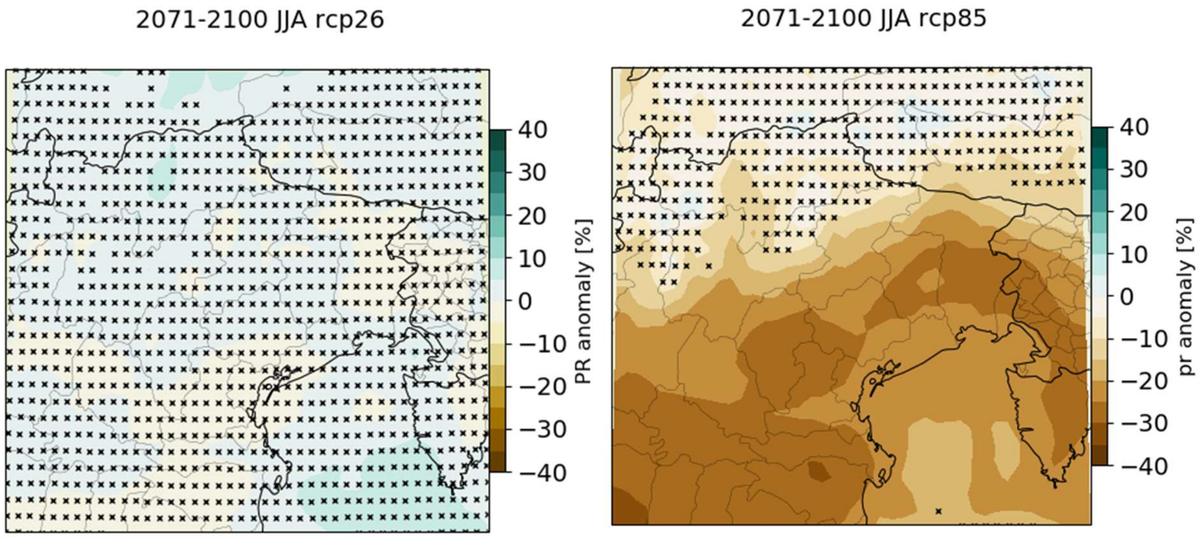

*Figure 11. Geographical distribution of the precipitation anomaly (units: percent of baseline value) in summer for the 2071-2100 with respect to the reference period 1976-2005; the left/right hand side refer to RCP2.6/RCP8.5. Crosses indicate the grid points where the model agreement is low.*

In order to assess the possible changes in the frequency of extreme events, the summer days SU30 and cumulative precipitation larger than 95th percentile R95pTOT are computed for the temperature and precipitation, respectively. Figure 12 shows the geographical distribution of the summer days anomaly (ensemble mean) for the far future with respect to the reference period. The most affected areas are the flat areas and the alpine valley at low altitude (such as the Valbelluna). For the RCP2.6 the anomaly stays below +10 days, on the other hand for the RCP8.5 it strongly increases to +60 days.

Geographical distribution of the anomaly of the cumulative precipitation larger than 95th percentile for the two forcing scenarios with respect to the reference one is shown in Figure 13 for winter. For RCP2.6 there is a positive R95pTOT anomaly but a good agreement among models only in a limited area in the south-east of Veneto (from +20 to +40%). On the other hand, for the RCP8.5 there is a (statistically significant) increase in the extreme precipitation in most of the domain, ranging from +60 to +80% in the coastal areas and from +80 to +120% in the Alps.

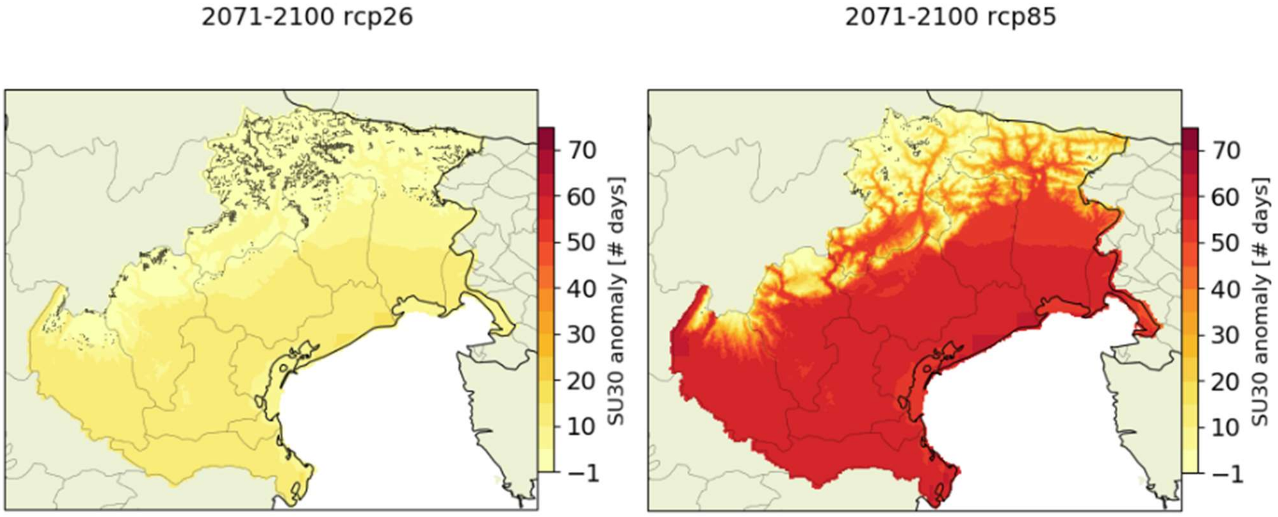

*Figure 12. Geographical distribution of the summer days anomaly for the 2071-2050 with respect to the reference period 1976-2005; the left/right hand side refer to RCP2.6/RCP8.5. Crosses indicate the grid points where the models agreement is low.*

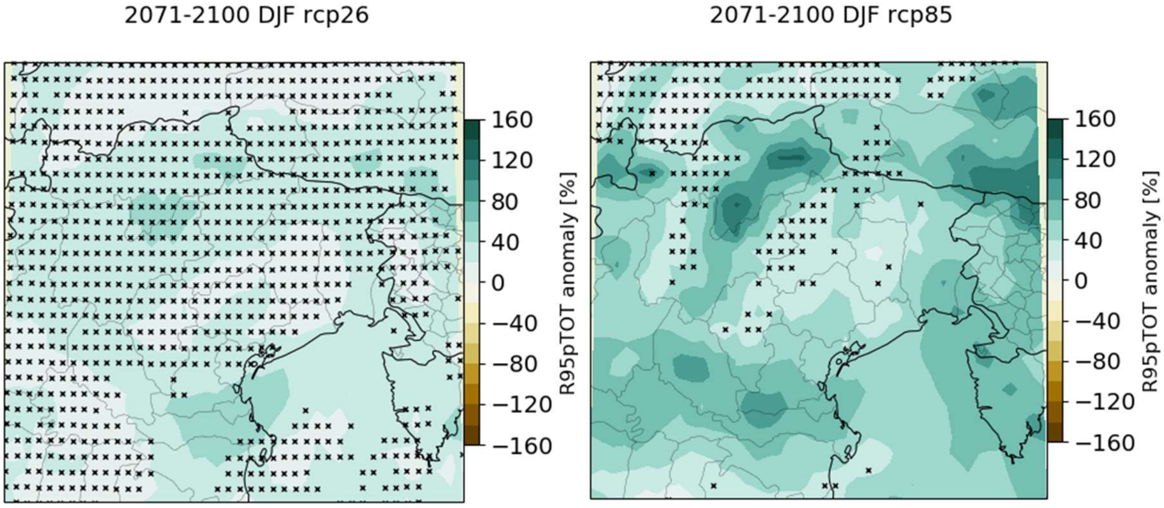

*Figure 13. Geographical distribution of the cumulative precipitation larger than 95th percentile (R95pTOT) anomaly (units: percent of baseline value) in winter for the 2071-2100 with respect to the reference period 1976-2005; the left/right hand side refer to RCP2.6/RCP8.5. Crosses indicate the grid points where the model agreement is low.*

Arpav, by exploiting both the WP4 knowledge on the data sharing system Erddap and fundings from other projects, has developed https://clima.arpa.veneto.it, a totally open-source web-gis platform on regional climate projections specifically suited for North-East Italy. The platform gives access to climate indicators in terms of maps, time series for specific locations, as well as gridded data (Netcdf) and point data (csv). It could be also further developed with the integration of historical climate data from regional weather networks and possibly other datasets (eg.: vulnerability, exposure, risk). This platform gives information on climate hazards at regional scale and it is aimed to support stakeholders, decision makers, citizens with respect to territorial planning, adaptation measures fostering the knowledge and awareness of climate change at local scale.

The underlying informatics infrastructure is based on inter-operable services, among of INSPIRE Directive Network Services and Open Geospatial Consortium services (e.g. WMS, WCS, Opendap) and can be federated with distributed network of DAP nodes (e.g.: Erddap, Thredds, Hyrax).

## Assessing vulnerabilities and risk predisposition from climate change

It is now widely established that climate change will increasingly have negative effects on our territory, contributing to the worsening of living conditions[1] in many areas and reducing the capacity of the territory to cope with increasingly frequent and intense shocks and stresses. However, not enough initiatives have yet been taken to counter these hazards and prepare for them. For climate change mitigation and adaptation to become more applicable in municipal policies and efforts, therefore, it is essential, and now a priority, that these concepts are incorporated and integrated within processes and tools - plans, strategies, programs, projects - that Administrations, at different levels, are equipping themselves with or have equipped themselves with. This implies that climate change adaptation and mitigation actions become *mainstream* in the policy apparatus of governments by including them in development programs, policies, or land management strategies[2]. The local process of climate adaptation must start with a necessary increase in the knowledge of territories concerning the effects of climate change: reading and observing places in terms of their spatial vulnerability to climate impacts requires data and information that are not always available in the cogent information repositories. Knowledge frameworks must therefore be enriched with new information levels useful for reading and understanding the climate phenomenon concerning the territory.

Considering a possible application of ARPAV's contents concerning the evidence of climate change on the Veneto territory, with this section, the process of defining a guideline that provides conceptual suggestions for the construction of adaptation strategies at the municipal scale following the mainstreaming approach begins. The guideline is established according to the operational logic of the AdriaClim project and tested in the construction phase of a model for the evaluation of

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[1] IPCC, Special Report Global Warming Of 1.5 °C, 2018

[2] How to Mainstream Climate Change Adaptation and Mitigation into Agriculture Policies, 2009, by Bockel, L., FAO

territorial multi-vulnerability (MV) - an evaluation condition extended to the concept of climate multi-impact - and, consequently, for the estimation of MR multi-risk (considered in terms of territorial predisposition). Both in the recognition of MV and MR the assessment procedure envisages the operational participation of different actors and local stakeholders, to initiate the construction of collectively shared adaptation processes. Ultimately, this approach reproduces a knowledge of local vulnerability that explicitly aims at strategic coordination of initiatives and knowledge coming from "below".

While mitigation addresses a broad context and a more global scale, adaptation, by its very nature, must mostly address the local needs of individual territories where climate change is having its effects: e.g. heat islands in specific locations or flooding in well-localized streets or areas. Responses, therefore, must strive for an increase in resilience both from the point of view of increasing the protection of citizens and the perceptible improvement (perceptibility criterion) of environmental and climatic conditions.

Phenomena associated with the climate and its change are increasingly central to the planning of cities and territories both for the physical effects they produce in the territories and in particular in urban areas and on the psycho-physical well-being of populations. Heat waves, intense rainfall, droughts, urban flooding, overflows, and threats to biodiversity on various fronts produce increasing and interlinked impacts that require up-to-date methods of adaptation planning to increase the capacity of territories to cope with increasingly frequent shocks and stresses.

To make this process efficient, cities - starting from the pilot cases selected by the AdriaClim project[3] - will have to experiment with new forms of the territorial government to respond to the climate problem, testing new models of data management and dissemination, as well as new information technologies. This process, until now, in the Italian context, has come up against considerable implementation difficulties, due to limits in planning skills, technical knowledge, and the availability of human resources, which municipalities often come up against in constructing climate change adaptation paths independently. The support of superordinate bodies - ARPAV, the Metropolitan City, the Region, etc. - and scientific institutes becomes central. - and scientific institutes become central.

Internationally accepted methodologies (Yabareen, 2013) over the years have led the United Nations *Framework Convention on Climate Change* (UNFCCC) to the preparation of a theoretical framework on adaptation as a practical and specific guide to support decision-making bodies structured in different steps that governments, both local, regional, and national, can undertake.

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[3] Municipalities of Jesolo, Cavallino Treporti (VE) and Porto Tolle (RO).

The growing attention towards climatic-environmental issues has led the collaboration between ARPAV, Iuav, and Ca' Foscari to act on several analytical and methodological grounds typically oriented towards the resolution of territorial urgencies through the construction of virtuous climate adaptation paths manageable in the medium and long term.

Specifically - in thematic continuity with the climate multi-impact assessment approach developed and summarised in the AdriaClim internal reports Iuav WP 3.5.1 and WP 5.4.5 - there is a choral will pursue a climate adaptation strategy on a municipal scale through the construction of "Guidelines" that allow local administrative action to integrate adaptation measures within the spatial planning and governance processes.

These guidelines are posed as a territorial learning model aimed at activating strategies and actions to improve resilience to climate change in transformation processes and urban resource management. Therefore, a conceptual model is suggested as an aid to climate design according to a comparison of operational principles able to establish systems and rules for the observation and evaluation of urban morphology.

The construction process is articulated on an initial phase of analytical discussion based on the study of territorial fragilities linked to converging climatic stresses (climate multi-impact conditions). Starting from this first analytical model, reflections follow for the spatial recognition of vulnerability conditions and, therefore, of territorial multi-vulnerability, achievable through the production of spatial information and the construction of apparently complex morpho-climatic scenarios with which to define general rules and criteria capable of implementing a logical framework of local adaptation actions.

With this in mind, the general guideline model considers four main vectors (or phases):

- favouring the construction of an integral vision of the impacts that climate change tends to generate on the morphological characteristics of urban space. The research and in-depth studies carried out by ARPA Veneto invite local administrators to evaluate the city as a system of values (economic, cultural, social) increasingly subjected to the growing impact of extreme meteorological events, while at the same time the vulnerability of the settlement organization increases with a consequent amplification of the possible damage to places and subjects (**Phase 1-Perception, ARPAV**);

- Orient the production of spatial information and morphological indicators useful for the elaboration of possible vulnerability and risk scenarios, capable of drawing adaptation models in terms of ecological, type-morphological, energetic, and environmental adaptation of the urban form. On the subject of risk, see also the evaluation method proposed by Ca' Foscari, based on the use of machine learning technology **(Phase 2 - Knowledge and Priorities, IUAV and Ca' Foscari)**;

- Promote the appropriation of spatial knowledge and spatial planning processes that, in a more or less explicit manner, may be relevant to climate adaptation issues (**Phase 3-mainstreaming, Iuav**) ;

- to support the formulation of a climate-related urban planning vocabulary, which allows the linking of local vulnerabilities to *climate-proof* tools for the governance of the city and the territory, as well as to bottom-up, spontaneous, and tactical actions. Added to this is the need to keep the territorial cognitive frameworks up-to-date, from which to identify priority areas of intervention on which to activate (through the drafting of project schedules) strategies and compensatory actions (**Phase 4-Action, Iuav**).

Phase 1 - already dealt with by ARPAV - has the task of emphasizing how the risks induced by climate change (CC) represent the phenomena that most clearly require innovative tools capable of steering territorial development towards a new planning and public decision-making perspective.

Phase 2 - the subject of discussion in this section . - draws attention to the need to propose and enhance spatial analysis procedures capable of identifying plausible scenarios of territorial multi-vulnerability with which to recognize priority areas for intervention and systems of actions for risk reduction.

Stages 3 and 4 - the subject of analysis in Chapter “Adapting to climate change: the urban planning response” - are finally dedicated to the construction of planning strategies oriented towards the search for new pluralist design and policy frameworks.

The rationale for recognizing territorial contexts that are vulnerable and/or predisposed to multi-hazard potential will therefore be taken up and enriched with a dedicated chapter, through a rethinking of concrete actions to adapt and improve settlement systems.

In Chapter “Adapting to climate change: the urban planning response”, ample space will be given to the principle of mainstreaming; an approach that will enable the development of autonomous and informed adaptation policies and programs.

## Models and concepts in assessing vulnerability to climate change

This section aims to guide the reader in recognizing morpho-climatic phenomena determined by the climate-territory relationship.

Enhancing the contents of the AdriaClim project, the following text provides a conceptual model of spatial analysis able to guide local administrations in the study of territorial vulnerability understood as a general condition of the fragility of the urban system linked to converging climatic stresses (multi-impact). Based on this premise, the research pathway reasons for the need to study vulnerability as the result of a logical product of different morphological behaviours.

Recognizing vulnerability in terms of cumulative fragility (multi-vulnerability MV) allows planning to be better oriented towards the definition of a set of compensatory measures (green, blue, grey, or policy) whose aim is to increase the overall resilience of the urban system. Achieving this objective will require the use of ad-hoc evaluation logic, constructed according to the different degrees of morpho-climatic criticality and concerning existing socio-economic suffering.

Looking at the scientific literature, vulnerability to climate change is defined as 'the degree to which a system is susceptible or unable to cope with the adverse effects of climate change' (Stocker, 2013), including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climatic variation to which a system is exposed, its sensitivity, and its adaptive capacity (see International Panel on Climate Change - IPCC and Climate Adapt). In this regard, however, it should be remembered that climate change is often not the only cause of vulnerability. Humans can increase their vulnerability through urbanization-intensive processes and land consumption or by building up resources in endangered areas.

The search for a new design linked to the recognition of multiple vulnerability conditions is linked to major environmental emergencies (climatic, but also economic, socio-cultural, or health-related) that highlight the inadequacy of traditional spatial planning models. These dynamics impose the need for a change in the planning paradigm, with the aim of anchoring *policies* and *design* strategies to the new challenges imposed by CC. In particular, the recognition of the influence of CC on urban landforms should foster and nurture a conscious use of new spatial information, directing spatial governance practices to consider unprecedented declinations of the concept of spatial adaptation, especially in terms of exposure and vulnerability (IPCC, 2014; IPCC, 2019) .

Various national and international research experiences consider new routes in the direction of adaptation, exploiting the potential for learning in information and technology facilitated by the presence of open-source data and the use of remote sensing analysis. The studies in the academic field show that assuming the reduction of vulnerability as an intermediate objective to the achievement of spatial adaptation, it is possible to activate heterogeneous experiments useful for the construction of information layers to support risk estimation and management (e.g. through the use of free information able to return spatial information archives built through free and participatory design processes: see Open Street Map - OSM).

However, although these studies are particularly innovative in the geographic mapping of territorial vulnerability, their methodological architecture tends to focus spatial research on impact measurement, delegating the critical-assessment investigation of the relationship between climate change and territorial systems (in terms of vulnerability and exposure) to specific tools supporting *governance* and territorial *design*. Considering that multi-vulnerability can be defined as a morphological response to multiple risks (multi-hazards), we recommend the use of spatial assessment practices conducted on the variety of territorial assets and their resilience *performance*, measurable with to the geographical logic of the CC (Maragno, 2023) .

To support this key reading, the recognition of territorial vulnerability should be anchored and developed around the following operations:

1. Recognizing the climate risks to which territory is potentially subjected (recognition of impacts).
2. Recognize the physical determinants that allow a climate performance to be associated with the constituent elements of the territorial project, thus contributing to the definition of territorial multi-vulnerability (construction of the territorial information framework).
3. Simulate the geographical behaviour of climate impact in relation to the morphological configurations of the urban fabric (construction of the spatial assessment model).

### Impact recognition and overlook

Before proceeding with a spatial analysis of spatial vulnerability (a procedure extensively introduced and described in Internal report Iuav WP3.5.1)[4] it is necessary that the assessment context is placed within a 'city-climate' analysis relationship that can be traced back to the recognition of specific climate impacts. From an evaluation perspective, the recognition of impacts enables a spatial link between climate risks and spatial multi-vulnerability profiles.

In this sense, the concept of MV can be represented based on the following function:

$$A_{MV} =(I\ , I_{12}\ ,...,I\ )_{nmh}$$

where,

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[4] Report for the development of an evaluation methodology (exportable and replicable) particularly suitable for pilot areas in Veneto (report delivered in October 2021).

$A_{MV}$ = 'thematic area', which describes the concept of multi-vulnerability (density, ecological values, infrastructure endowment, morphotypes, etc.) as a function of impacts $I_i$ (e.g. heat islands, urban flooding, storm surges).
mh= multi-risk.

The MV concept guides the work in this direction: mh is the result of the observation of climate data (to address this issue, the information and projections prepared by Arpa Veneto must be taken into account) and their changes. The climate changes considered dangerous for infrastructure, the environment, society, and the economy define local impacts ($I_i$). MV is not understood as a mere 'damage orientation', but as a concept that defines the conditions for generating a spatial context potentially exposed to a multi-hazard climate. MV is an extension of the concept of 'damage propensity', with operational implications on the specific and differentiated critical issues related to climate change. In the AdriaClim project, the recognition of multi-vulnerability considers three types of impacts: UHI, UF, and Ss. The choice to analyze multiple impacts pushes the present research and the AdriaClim project to go beyond approaches oriented to the analysis of single impacts, highlighting the need for assessment models capable of defining the spatial interaction between urban morphologies and the risk equation.

## A coordinated data collection approach

Multi-vulnerability is to be defined through a selection of environmental variables (land uses, slopes, densities, cover, urban morphotypes, etc.) that can assess and weigh morphological impacts attributable to converging climatic stresses. The development of assessment methodologies can make use of information and data from heterogeneous sources. Some data are obtained through the application of *remote sensing analysis* algorithms, while others may come from *geocoding* activities and pre-packaged spatial information available in regional, provincial, and European work/research settings.

By way of example and without any claim to exhaustiveness, the following is a list of information layers and base maps used by the AdriaClim project for multi-vulnerability analysis, exposure assessment, and multi-risk estimation (Table 1).

*Table 1 - Data collection used to calculate MV and MR*

| Information level | Type | Resolution | Source | Year |
|---|---|---|---|---|
| Vegetation Health Index (VHI)* | Raster | 30m x 30m | Landsat 8 (United States Geological Survey-USGS) | 2020 |
| Map of runoff coefficients (MCD)** | Raster | 30 m x 30 m | IUAV | 2018 |
| Digital Terrain Model (DTM) | Raster | 25 cm x 25 cm | Cities<br>Venice Subway | 2014 |
| Imperviousness Density (IMD). | Raster | 10m x 10m | Copernicus Programme | 2018 |
| European Settlement Map (ESM) | Raster | 2m x 2m | Copernicus Programme | 2015 |
| Soil cover and soil suso database | Shapefile |  | Wind Region | 2018 |

| | | | |
|---|---|---|---|
| Urban activities | Shapefile | OpenStreetMap (OSM) | 2021 |

*Elaboration *by the authors conducted on multispectral image "LC08_L1TP_191029_20200730_20200807_01_T1"*
***Elaboration on Veneto Region Land Cover Database (CCS 2018)*

By combining the definition of impacts with spatial matrix data, it is possible to define an evaluation approach that allows the spatial domain of MV to be recognized.
Specifically, the use of data from Table 1 has a threefold purpose:

- characterize the meta-criteria concerning the nature of the climate impact;
- defining the criteria of judgment with which to evaluate the semantic domain;
- Evaluate and describe the relationship between urban morphologies and their susceptibility to a given climate impact.

The use of data and information from open-source spatial infrastructures is suggested. This choice makes it possible to carry out a punctual check on public utility services (transport network, safety, health, education, etc.) by exploiting digital cartography inserted in shared communication platforms open to institutional and social monitoring and control. This enables the development of a flexible, integrable, and replicable methodological procedure, thus becoming a valid support tool for territorial governance.

The AdriaClim project procedure uses satellite-derived data and pre-processed morphological data from the Copernicus EU Earth observation and monitoring program. The added value of these information models makes the spatial analysis open, integrable into the continuum, and directly comparable[5] .

## How to evaluate

Assessing territorial multi-vulnerability stems from the need to analyze the effects of climate change (CC) on the territory as a cross-sectoral and multi-level issue (both in policy and planning terms). The assessment of MV should therefore assume a multi-dimensional character, fuelled by the need to assess territorial fragility conditions through multi-attribute survey techniques[6] : these are exploratory practices oriented towards the construction of decision-making models based on

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[5] The increased potential for treating and processing data acquired from remote sensors favours the development of new and unprecedented survey techniques that can be easily updated with new information deposits from the digitisation processes of the territory. The use of new survey techniques in remote sensing solutions makes it possible to integrate information deposits with new multi-source data and to provide scientific research with exhaustive and complete data, which are also indispensable to better orientate the choice of information criterion in relation to the survey demand.

[6] MV is presented as a multi-criteria spatial evaluation model using morphological variables as decision criteria.

techniques for multi-criteria spatial analysis (MCE - GIS). The advantage of using a multi-criteria evaluation model (in this case the criteria refer to spatial information of both a structural and organizational nature) lies in the fact that a large number of information layers from heterogeneous sources can be considered simultaneously. From an operational point of view, this strategy helps to change the planning paradigm, with the aim of anchoring policies and design strategies to the new environmental challenges imposed by CC. Pluralist assessment and participatory practices oriented to the definition of priority areas of intervention for urban adaptation make use of this paradigm.

As with the methodology adopted in AdriaClim, the multi-vulnerability analysis should be developed according to a spatial multi-criteria approach to correlate and transform geographical input data into decision output through a comparative approach.

This approach introduces a design-led evaluation process capable of recognizing systemic relationships and arguing their morpho-climatic connections.

### Methodological Insight

As already mentioned, in the AdriaClim project the definition of MV is based on the study of three different types of impact: UHI, UF, and Ss. To this study is added an analytical-interpretative procedure for the choice of morphological variables useful for the characterization of MV in the three impact classes. The characterization of MV is defined by selecting a *core set* of morphological criteria, suitable for the recognition of vulnerability in a multi-impact key. In Table 2 below is a logical association between MV semantic domain, interpretative meta-criteria, and evaluation criteria.

*Table 2 - Data collection used to calculate MV and MR*

| **Semantic domain** | **Interpretative meta-criterion** | **Evaluation criterion** | **Criterion Definition** | **Format and metrics of the criterion** | **Metrics** | **Value Range** | **Notes** |
|---|---|---|---|---|---|---|---|
| **MV** | UHI | Vegetation Health Index (VHI)* | Vegetation health indicator | Raster image | % | 0 - 100 | High values identify water stress conditions |
| | UHI, UF, Ss | Imperviousness Density (IMD). | Level of sealed soil | Raster image | % | 0 - 100 | High values identify highly sealed areas with little vegetation |
| | UF, Ss | Runoff coefficient map (MCD) | Spatial association between runoff coefficients and land uses (CCS) | Raster image | % | 20 - 90<br>(0,2 - 0,9) | High values identify urban *flooding* conditions |
| | UF, Ss | Digital Terrain Model (DTM)** | Digital map of land elevation distribution | Raster image | Altimetry in cm | -100 - +200 | High values identify areas most susceptible to storm surges and flooding |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | UHI, UF, Ss | European Settlement Map (ESM). | Map of human settlements | Raster image | Dichotomous spatial information | [0,1] | Value 1 identifies a high concentration and compactness of constructions |

* VHI is considered a satellite index capable of recognizing vegetation cycles and areas with good vegetation health. However, in this research, VHI is considered a criterion of environmental criticality, recognizing surface areas that are more susceptible to being affected by heat waves. In this case, values corresponding to the complement of 100 are used. A reversal of the values is necessary.
** DTM values are reversed. High values identify urban and coastal areas with relatively low altitudes.

The selection returns a varied set of metric dimensions. High values help to identify areas that are more likely to experience spatial *stresses* related to adverse climate scenarios.
This analytical logic favours the construction of a multi-attribute spatial assessment model by exploiting morphological variables as decision criteria capable of rendering the propensity of spatial systems to be adversely affected by a multi-impact climate.

Given the different metrics of each criterion, normalization is essential to limit the excursion of values within ranges, or ranges, that are irrelevant to weighting. The result of this procedure expresses the overall suitability of the criteria in recognizing morphological states and uses that are inherently predisposed to be damaged by possible, and probable, multi-impact climate conditions.

Through the use of multi-criteria decision-making methods (see the AHP method used in report WP3.5.1) [7] the procedure proceeds to organize the assessment in a hierarchical form, assuming environmental descriptors (density and morphologies) as evaluation criteria for the weighting and choice of geographical areas most prone to impact. The multi-criteria analysis of data applied to the study of spatial relations makes it possible to map the possible link between climate and territory, facilitating the anchoring of climatic *stressors* to the organizational and settlement form of the urban context. The multi-criteria study identifies plausible scenarios of territorial multi-vulnerability governable by a deliberative component fuelled by multi-actor assessments and decision-making paths.

The use of raster models, together with a weighted linear combination with preference ratings, finally allows the aggregation of the five evaluation criteria and the construction of the *suitability* map MV (Figure 14).

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[7] The AHP technique is developed through the application of a hierarchical analytical model, which allows a set of alternatives to be evaluated in the presence of multiple criteria. It is a reticular analysis model that is developed on several levels through a dominance hierarchy, in which the evaluation problem is broken down into sub-problems of an easier dimension to solve.

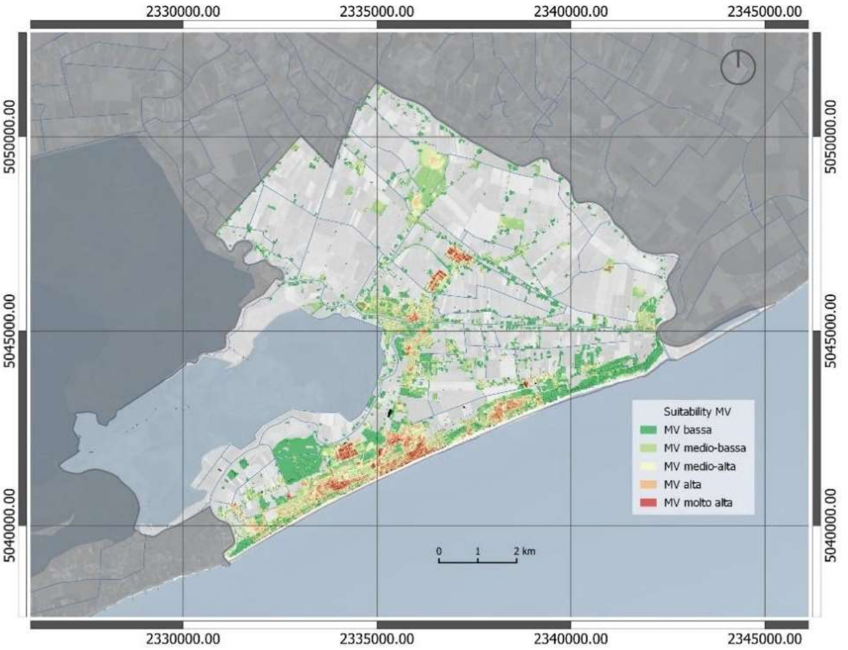

*Figure 14. Multi-vulnerability (MV) map of the municipality of Jesolo*

## A framework for assessing urban risk predisposition to climate change

To complete the assessment of the effects of climate change on spatial, settlement, and environmental components, it is advisable to combine the multi-vulnerability information with the spatial value system (exposure). The spatial convergence between multi-vulnerability and exposure represents a valid indicator of local multi-hazard, useful to establish management and planning priorities for urban and territorial spaces. The latter process makes it possible to orient the contribution of evaluation research towards a spatial analysis perspective based on the use of increasingly interpreted, integrated, and systemic spatial information.

As the issue of climate change is increasingly a multi-level and cross-sectoral condition, the experimentation with multi-systemic spatial assessment could raise awareness of the use of multi-objective information in training practices and planning to support pluralistic decisions concerning the strategic definition of multi-risk.

From a planning point of view, this analytical approach is a valuable tool for developing learning paths and evaluative languages increasingly transversal to the new dimensions of climate adaptation, with a whole series of methodological, technical, and technological experiments and discussions.

Therefore, to introduce and address the issue of risk, this guideline recognizes the need to develop two operations:

1. Assessing the exposure levels of a territory subject to a potential multi-impact climate.
2. Developing a multi-risk estimation to be used as a tool to guide public decision-making in new *policy* domains (understood as multilevel and multi-actor forms of spatial coordination).

Concerning the profile of these two operations, the methodology developed by AdriaClim favours the following operational reflection.

**Methodological Insight**

The spatial convergence between vulnerability and exposure is a valid indicator of local multi-hazard (MR) susceptibility, useful for setting management and planning priorities for urban and territorial spaces.

The concept of multi-hazard susceptibility considers the propensity of a given system (in terms of physical and morphological characteristics) to suffer potential damage expected following the occurrence of a particular extreme climatic event.MR is given by the following matrix relationship:

$$MR=MV*P\ *E$$

where:

MR: multi-risk predisposition;
MV: morphological predisposition of the territory to multi-vulnerability;
P[8] : hazard of the climatic event on the urban system (variable assessed in relation to the type of impact dealt with and its potential relationship with urban morphology)[9] ;
E: exposure (population exposed to the negative effects generated by a climate impact: land features; activities; human lives; etc.).

As mentioned earlier, the innovative aspect refers to how the urban component is monitored and evaluated under conditions of exposure and susceptibility to climate risk. The use of open-source spatial platforms, such as OSM, makes it possible to carry out a timely and up-to-date assessment of utilities. This enables the development of a flexible, integrable, and replicable methodological procedure for the

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[8] Risk results from the interaction between vulnerability (of the affected system), exposure and hazard (IPCC, 2014). In order to assess the hazard and the probability of its occurrence, it is necessary to have reliable estimates of weather-climate *trends* and the intensity of extreme events (*hazard*). The use of this information could make an important contribution to urban multi-hazard management. However, for its proper use the impact of climate change should be anchored in the study of multiple morpho-climatic scenarios. The observation of climate trends is therefore useful if appropriately cross-referenced with local morphological factors.

[9] For example, with an absence of the estimate of P the risk does not go to zero, but becomes equal to MV, both in terms of possible occurrence and intensity.

estimation of climate multi-hazard susceptibility (the relationship between multi-vulnerability and exposure), thus becoming a valuable support tool for local governance (Figure 15).

The link between the results of the analysis and local planning is made based on the information infrastructure made available by the regional authority, the Land Cover Map.

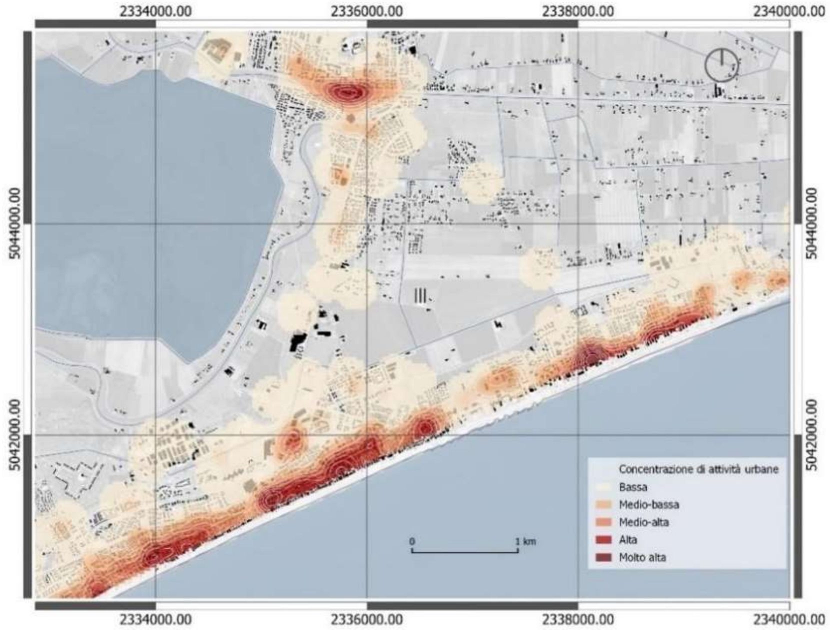

*Figure 15. Urban activity density broke down into five classes using the natural breaks method*

The analytical-descriptive framework produced, which considers the territory from both a geo-morphological and socio-economic perspective, can find its operational dimension within guiding tools for the construction of sets of measures for climate change mitigation and adaptation. By giving local planning an ex-ante cognitive level, multi-hazard engages with the territory thanks to the matrices linking on the one hand solutions and the other hand the information level of land cover. In this way, the grafting of solutions and the launching of new practices can take place in a calibrated and conscious manner, precise thanks to the identification of homogeneous areas that therefore allow the perimeter of hotspots within which adaptation initiatives can be launched in a prioritized manner, also according to the density of economic activities exposed to risk (Figure 16).

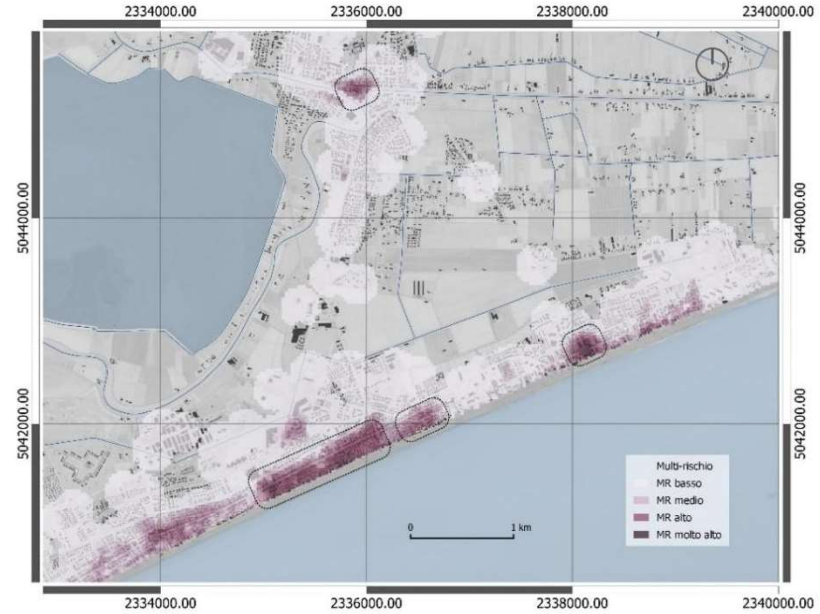

*Figure 16. Multi-hazard map* [10]

This intervention logic is proposed as an open technical solution, which will necessarily be followed by the operational design phase. The objective is to facilitate choice and stimulate comparison and recombination that, from a systemic resilience perspective, ensures the improvement of urban performance (information, security, and resilience).

In conclusion, the proposed assessment pathway emphasizes the use of new technologies and their integration with different techniques and forms of spatial assessment. Moving down to the project scale, the construction of a multi-criteria cognitive apparatus facilitates the interpretation of climate impacts at the urban scale. The research results advise local administrations to work through participatory working tables to actively involve different stakeholders in the construction of collectively shared CC adaptation processes.

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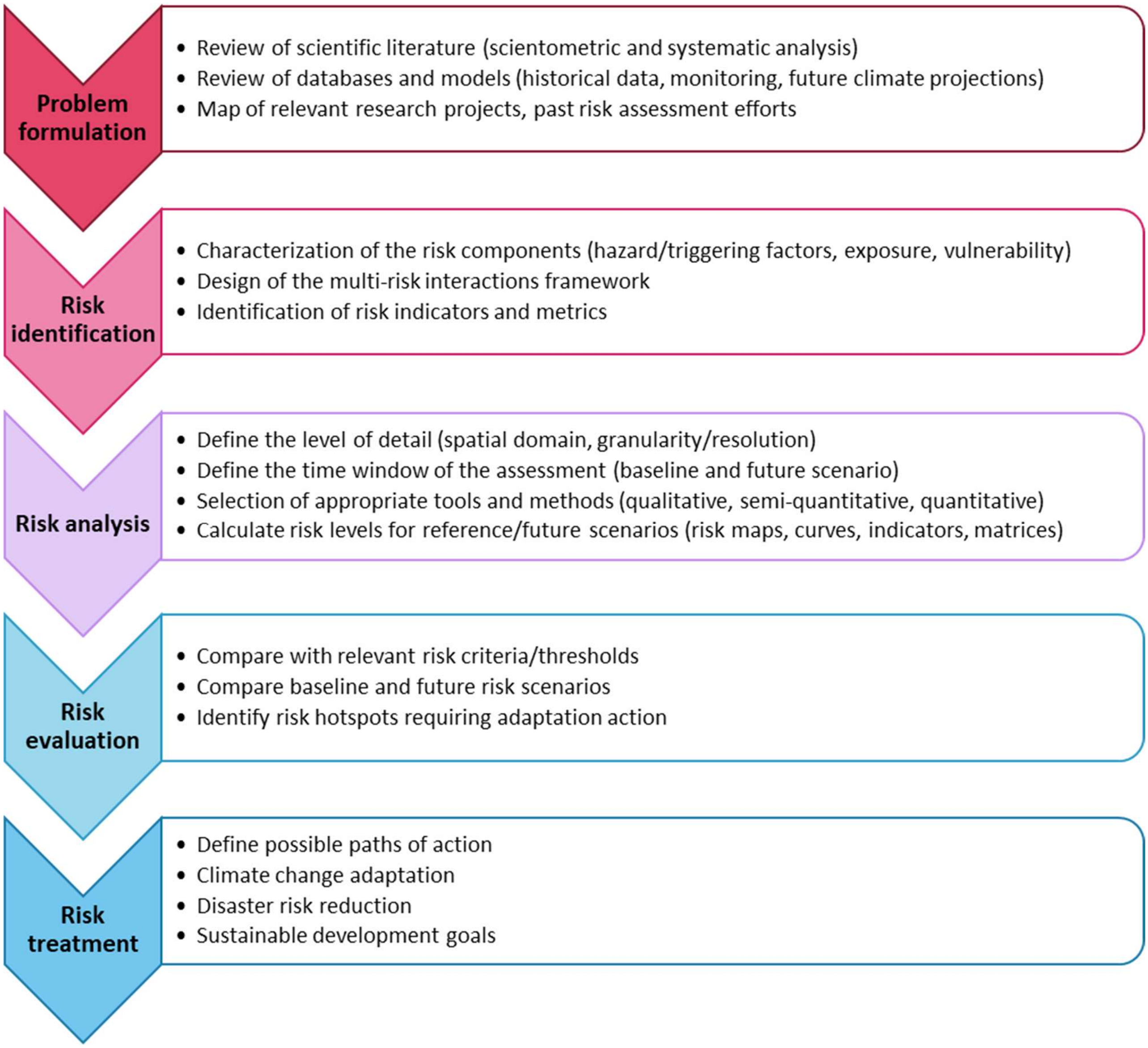
[10] MR is represented by an index with values ranging from 0 to 1, where 0 indicates zero MR and 1 maximum MR. MR values are grouped into four qualitative classes: low MR; medium MR; high MR; very high MR. The classification uses a quantitative comparison criterion, evaluated and weighted according to the characteristics of the statistical distribution of the variable (MR).

## M**ult**i-**risk** assessment in the Veneto pilot

The climate change risk and vulnerability assessment methods applied in the Veneto pilot, follow the principles of international and European risk assessment guidelines in the field of climate change adaptation and disaster risk reduction (EC, 2019; EEA, 2018; Poljansek et al., 2019), and of the international ISO standard for the selection and application of risk assessment techniques (ISO 31010, 2018).

Risk and vulnerability assessment should help to reach a common understanding of the risks affecting a country or a region, as well as their relative importance (priority) according to present (reference) and future scenarios. The identified, assessed and prioritized risks and vulnerabilities are then the basis for the risk management and climate adaptation planning, and the successive implementation of adaptation measures.

As shown in the following scheme, the research activities in the Veneto pilot followed a general risk assessment approach that, according to the international guidelines ISO 31010 (ISO, 2018), can be divided into 5 main ***problem formulation***, ***risk identification***, ***risk analysis***, ***risk evaluation*** and ***risk treatment***.



**Problem formulation**

- Review of scientific literature (scientometric and systematic analysis)
- Review of databases and models (historical data, monitoring, future climate projections)
- Map of relevant research projects, past risk assessment efforts

**Risk identification**

- Characterization of the risk components (hazard/triggering factors, exposure, vulnerability)
- Design of the multi-risk interactions framework
- Identification of risk indicators and metrics

**Risk analysis**

- Define the level of detail (spatial domain, granularity/resolution)
- Define the time window of the assessment (baseline and future scenario)
- Selection of appropriate tools and methods (qualitative, semi-quantitative, quantitative)
- Calculate risk levels for reference/future scenarios (risk maps, curves, indicators, matrices)

**Risk evaluation**

- Compare with relevant risk criteria/thresholds
- Compare baseline and future risk scenarios
- Identify risk hotspots requiring adaptation action

**Risk treatment**

- Define possible paths of action
- Climate change adaptation
- Disaster risk reduction
- Sustainable development goals

*Guidelines for the implementation of the climate change risk and vulnerability assessment in the Veneto pilot (Adapted from ISO 31010 (2018).*

The ***problem formulation*** aimed at setting the context of the risk assessment, defining the issues at stake, through a systematic literature review of main climate change hazards, vulnerabilities and impacts in the coastal area of Veneto.

The following ***risk identification*** phase analyzed existing risk information and knowledge to find, recognize and describe the main risks to be reduced in the investigated area, their components (i.e., hazard, exposure, vulnerabilities, triggering factors) and potential interactions.

Then, the ***risk analysis*** supports the combination of the risk components of hazard, exposure and vulnerability to determine the level of individual or multi-hazard risks in the affected region. According to the purpose of the analysis, an innovative Machine Learning approach was designed to assess climate risk estimating the annual risk frequency under RCP8.5 future climate change scenarios until year 2050 (as detailed in Deliverable *D5.4.5 'Multi-risk assessment in the Veneto Region pilot area: comparative analysis and prioritization of main impacts, vulnerabilities and risks related to climate change'*), thus supporting the evaluation of tailored adaptation strategies for the Veneto case study.

The outputs of this analysis (risk maps, curves, indicators etc.) are then considered in the ***risk evaluation phase***, comparing risk levels across different risk criteria and scenarios, to determine whether further risk management actions are required (ISO 31010, 2018).

The risk evaluation phase finally supports policy and decision makers in the final ***risk treatment***, where guidelines for the definition of climate adaptation actions, risk management plans and sustainable development actions are developed (as detailed in Deliverable *D5.4.8 'A dashboard to support the planning of adaptation to climate change for the Veneto project area able to allow self-assessment of the current territory planning and health policy for searching adaptation actions already in place'*).

## Adapting to climate change: the urban planning response

Adaptation can be interpreted as the result of a continuous process of learning and response (whether passive, reactive, or proactive), which requires a considerable commitment to collaboration and the creation of spaces for social learning, to increase the capacity to effectively interpret different social and environmental contexts, institutional arrangements, practices and commitments of the many stakeholders and the ability to develop new policies and concerted actions[11] .

We can say, therefore, that these responses will have to materialize with the increase of resilience both from the point of view of increasing the protection of inhabitants and visitors and of the constant and continuous improvement of the environmental and morphological conditions of the city. Climate adaptation is only the outcome of a complex interaction between the components of a community: to arrive at the operational framework and, therefore, operate with adaptive measures, it is necessary to involve local actors and structure a participatory planning process, which takes into account both the needs of the urban economy and the intensification of weather-climatic phenomena.

Participation, however, must be a principle at all stages of the process: from the definition of adaptation goals to implementation and monitoring. During these steps, getting citizens, associations, authorities, and administrations to participate as actively as possible, also integrating different points of view, contributes to the soundness and effectiveness of the whole process.

At a territorial level, climate impacts can be defined as ***shocks*** - i.e. single, sporadic events - or as ***stresses*** - i.e. pressure conditions that last in that specific territory and that affect specific socio-demographic sectors, sometimes even heterogeneous among themselves, which are already compensated for by the vertical coordination among the competent authorities in environmental matters (such as the Regions and the Basin Authorities). We speak of verticality when we refer to the planning system that deals with this type of impact, which, organized according to a territorial hierarchical framework, has the task of directing the subordinate structures and coordinating them with each other in the function of proper land management. Based on this, we can also say that the system is activated during intense climatic events, providing a response apparatus that already exists in itself but that, implicitly, is forced to submit to multilevel limits and regulations[12] , sometimes not yet prepared to manage the progressive change of climatic conditions and what this entails in terms of relapses and identifiable impacts.

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[11] Regional Climate Change Adaptation Strategy, Region of Sardinia, DGR no. 6/50 of 5 February 2019.

[12] For example, when we talk about water resource management and vertical guidelines, we are referring to the principle of subsidiarity according to which the local authority must transpose guidelines from the regional and basin authorities.

Due to the complex interrelationship between the natural environment, government agencies, social partners, and stakeholders, local authorities are called upon to outline more specific adaptive responses that are aware of the progressive intensification of possible disturbances. Therefore, as different policies and practices are being reorganized, the types of response that can be provided when it comes to adaptation will also be different.

The three types of approaches that can be activated for adaptation[13] are in fact:

- **Incremental**: In the case of limited climate anomalies, signs of change are difficult to distinguish because they are confused with natural climate variability. In these situations, it is sufficient to improve the accuracy of managing already known risks, rather than trying to identify completely new (and uncertain) solutions. This type of adaptation can be framed as incremental, based on experience gained from observing what has happened in the past in a highly variable climate. Incremental adaptation measures are what people have already experienced and are familiar with.
- **Systemic:** It can be configured as a strategic adaptation option that acts, through behavior and technology, but not necessarily irreversibly, on the fundamental elements of a system in response to changes in climate that are well perceived and whose effects challenge sustainability at the system scale.
- **Transformative**: This is the strategic option of adapting to climate pressures so severe that they change the fundamental attributes of a system and necessitate the design of a pathway that can lead to profound transformations to respond resiliently to expected impacts.

However, for **climate change adaptation to** become a structural process for a territory's development, it **must be incorporated** into plans and strategies at different levels, making climate change a mainstream issue within the territorial government framework. However, to address such a pluralistic and participatory process, it is necessary to succeed in using a uniform and replicable assessment approach, in time and space, without burdening the existing land governance machinery.

In this sense, the multi-risk model generates new opportunities for adaptation in spatial planning: it allows the recombination of the variables exposed within a univocal weighting matrix, which considers the weather-climate factors as detractor elements, whose co-presence leads to the multiplication of the risk factor precisely where the exposure is highest, to favor of measures that are typologically coherent with the urban (or rural) reference fabric. Therefore, the participatory process for the diffusion and mainstreaming of climate adaptation is grafted to support the

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[13] The definitions are extracted from the "Guidelines for Regional Climate Change Adaptation Strategies" (Action C2 of the LIFE Master Adapt project), defined with the contribution of the "EEA Report No 12/2016 - Urban adaptation to climate change in Europe 2016 - Transforming cities in a changing climate".

framework of territorial reconnaissance, of human activities and socio-economic assets that can be considered at least susceptible to a certain degree of climate-induced disturbance, for example, tourist operators, public service places or commercial and manufacturing activities.

In essence, to respond to the changing climate, it is necessary for the local level actors interested in initiating an adaptation pathway to reorganize themselves to **structure their course of action according to the multiple impacts** to which their territory is vulnerable. Cities and spatial planning authorities need to orient their tools toward the following operational steps:

1. **Reconnaissance phase: the importance of the Adriaclim model for multi-risk calculation.** To get to know the territories and their peculiarities from a morpho-typological and socio-economic point of view to structure an in-depth knowledge of the territory and urban fabrics (elaboration of the climatic cognitive framework, multi-vulnerability assessment, and determination of the portions of territory subject to multi-risk);
2. **The analysis phase of the spatial government structure and mapping of existing plans:** analyzing existing planning instruments and involving stakeholders in the local adaptation process (stakeholder participation and involvement, mapping the competencies of administrative structures, mapping national, regional, supra-municipal, and municipal plans and programs);
3. **Definition of adaptation goals within a participatory process:** developing adaptation targets to focus on the targets to be achieved by adopting an overall view (transposition of international, national, and regional targets, definition of specific local adaptation targets)
4. **Integration of adaptation actions into plans and programs at the local and territorial level:** For planning, this corresponds to operational programming of the actions contained in the Abacus of Measures or to the enhancement of adaptive features where they are already present (actions, guidance for the integration of adaptation into plans and programs
5. **Cyclical monitoring of factors exposed to multi-risk:** reporting on the progress of the process with a performance benchmarking of the implementation of the adaptive measures in agreement with the process actors-partners;

## Reconnaissance phase: the importance of the Adriaclim model for multi-risk calculation

The first phase to proceed with the dissemination of adaptation practices, therefore, is the reconnaissance of the values in play on a territorial scale, of the socio-economic aspects, of the climatic dynamics that insist in the area considered, both by systemizing the existing information coming from the instruments in force and by obtaining new and updated information. The information should be taken **for the entire area of competence of the aggregation, taking into account the geographical specificities of each sub-municipal context**.

An effective **adaptation process from the outset** must aim to **cope with** specific impacts resulting from climate change[14] such as, for example, heat waves and heat islands, rising mean sea levels and urban flooding **needs to get to know the affected territory in detail** (Figure 17). Bearing in mind the distinction between shocks and stresses exposed above, we can define these as the outcome of the recombination between a hazard source (or several, also called hazards) and the morphological, functional, and socio-demographic characteristics of the territory.

Some of the priority information to be known is, for example:

- **climate**: historiography of meteorological events of particular interest, climatic evolution (weather, temperatures, winds, rainfall, etc.);
- **demographics**: population, age groups, births, immigration and emigration rates, employment situation, etc;
- **environmental**: valuable areas (SCIs, SPAs, etc.), ecological corridors, agricultural vocations, etc;
- **socio-economic**: productive fabric, employment, etc;
- **urban** planning: main perspectives of the plans insisting on the territory (PTCP, PS, etc.);

Much of the information, as well as the subsequent target-setting phase, could be derived from reading the **cognitive frameworks of municipal plans** as well as from **documents on a super-ordinate metropolitan and regional scale, in order** also to substantiate the **vertical *mainstreaming*** process outlined above.

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[14] For more information, see the D5.4.5 ‘Multi-risk assessment in the Veneto Region pilot area: comparative analysis and prioritization of main impacts, vulnerabilities and risks related to climate change’.

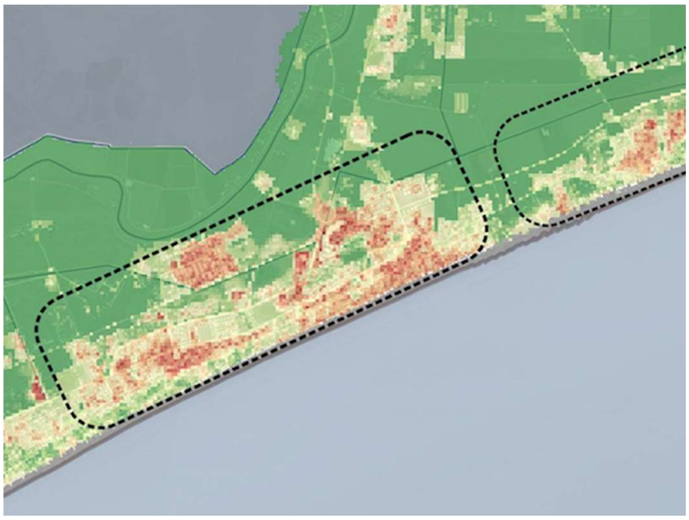

*Figure 17. Extract from the cartography identifying the predisposition of the territory (Suitability) with respect to the multi vulnerabilities present in the municipality of Jesolo (urban heat island, predisposition to flooding from heavy rain and damage from sea storms)*

With the Adriaclim method, a multi-risk assessment approach was tested for the creation of digital knowledge frameworks whose contents are characterized by the recombination of climate and socio-demographic scale variables. For the public administration, the operational contribution within a mainstreaming process is certainly among the most important to substantiate the role of coordination and direction, from the formation of the database to the validation of the information extracted through MDG mining, but also to the identification of public and private actors to be involved during all phases (see Figure 18).

*Figure 18. Fragment of cartography of the Municipality of Jesolo showing the points of interest extracted by mining from OpenStreet Map. In this image, it is possible to appreciate the density of economic activities and services that have been considered to estimate the density of elements exposed to Multi-Risk (MR)*

At present, the Adriaclim model considers the possibility of integrating the OSM database, an open and accessible information source, which collects and catalogs to a functional parameterization linking spatial location and typological identification of the exposed element. However, in a participatory process, the mapping of multi-hazard exposed elements can be localized and integrated through the collection of bottom-up knowledge from local stakeholders, i.e. from all interested parties, who can validate the extent and incidence (Figure 19).

An adaptation process, to be initiated in a densely urbanized environment such as that of the Veneto coast, must equip itself with the metrics with which to consider different adaptive hypotheses about the address objectives. Adaptation, in this context, means acting by considering operational lines concerning urban fabrics with a high presence of residential, tourist-receptive buildings, commercial activities, and public services but, at the same time, also measures dedicated to natural coastal areas, where there are a high landscape quality and where habitat conservation becomes the added value of the overall operation.

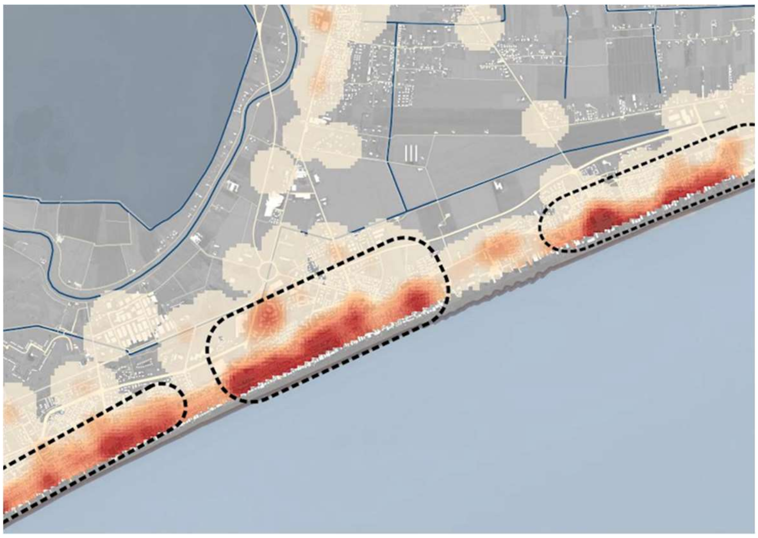

*Figure 19. Extract of cartography containing the density estimate of the OSM points, conducted on the Municipality of Jesolo using kernel density algorithms, to spatially identify the contexts richest in elements potentially exposed to the MR (which is shown in the next image, Figure 4). This image represents one of the variables with which the multiple risk factor will then be calculated and supports the structuring of the adaptation process by orienting it towards targeted planning of those that may represent stakeholders for the initiation of policies and practices in response to the changing climate to be included in urban governance.*

The first step is to create a list of potential stakeholders to be involved, also depending on the topic to be investigated:

- offices and sectors of the different municipalities;
- national, regional, and metropolitan.
- private sector: companies, consultancy firms, foundations, etc;
- civil society and associations within the member municipalities;

In this sense, the plurality of actors and morphologies represents the design driver behind the Adriaclim method for studying multi-risk (Figure 20). As mentioned above, for the definition of the elements exposed, the model is based on the constitution of an open source and common information base among several identity profiles, ranging from the public entity to the commercial operator; subsequently, it metabolizes the background information related to morphological formations which, weighed together with impact climatic forcings (high temperatures and extreme rainfall) generate what is the multiple risk scenario :

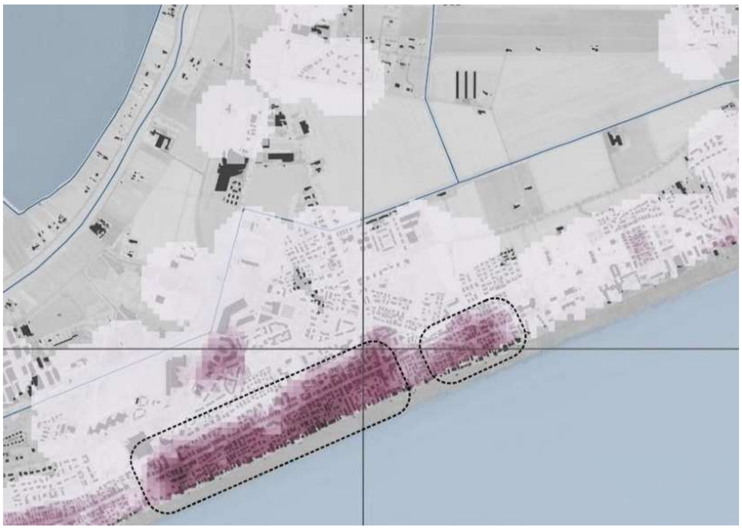

*Figure 20. The extract of the multi-risk map, in this case, carried out in the municipality of Jesolo, makes it possible to interpret the territorial portions according to a certain multiple risk factor, in particular High and Very High. This spatial re-interpretation allows the leading bodies of the adaptation process to re-interpret their territory reordering it according to the appropriate intervention priorities. The MR will then be juxtaposed with the Abacus of Measures, which will help in the choice of devices to be deployed in response to climate impacts by exploiting their link with the types of land use and land cover within which their application is considered effective.*

The outcome of the interactions between the weights attributed to the components of the evaluation model makes it possible to hierarchize the territory, according to an overall vision, which supports the adaptation process, leading it toward the characterization of the portions at risk to direct expenditure (in terms of time and monetary resources) favoring the adoption of adaptation measures that are strongly compatible with the context in which they are proposed (Table 3).

*Table 3. Multi-risk assessment results for the municipality of Jesolo: distribution of the number of activities subject to a high and very high-risk level.*

| **Macro-categories of activity** | **Number of activities in the macro-category** | | **Activities subject to high and very high multi-hazard** | |
|---|---|---|---|---|
| | n. | % | n. | %* |
| 1- Culture, entertainment, and the arts | 10 | 1,18 | 5 | 50,00 |
| 2- Historical elements | 3 | 0,36 | 0 | 0,00 |
| 3- Finance and Communications | 22 | 2,61 | 11 | 50,00 |
| 4- Gastronomy | 172 | 20,38 | 33 | 19,19 |
| 5- Waste Management | 128 | 15,17 | 21 | 16,41 |

| | | | | |
|---|---|---|---|---|
| 6- Health Services | 23 | 2,73 | 3 | 13,04 |
| 7- Mobility | 174 | 20,62 | 19 | 10,92 |
| 8- Shops | 78 | 9,24 | 23 | 29,49 |
| 9- Administrative services | 4 | 0,47 | 2 | 50,00 |
| 10- Leisure and sport | 22 | 2,61 | 0 | 0,00 |
| 11- Tourism and accommodation | 205 | 24,29 | 74 | 36,10 |
| 12- Schools | 3 | 0,36 | 0 | 0,00 |
| **Total** | **844** | **100%** | **191** | **22,63** |
| * Percentages of high and very high multi-risk of each macro-category, made up of one hundred total assets | | | | |

The logical-consequential development takes place taking into consideration the dual relationship between the multi-risk maps and the geometries of the Land Use and Cover database prepared by the Veneto Region. The work of hierarchization of the multi-hazard takes place during the final stages of the model, according to a scale that goes from Low MR to Very High MR and represents the conclusion of the reconnaissance path of explication of the local morpho-climatological variables. In this report, the Land Use and Cover map becomes functional to the reconnection between the environments at risk and the adaptive solutions contained in the solutions abacus (Figure 21).

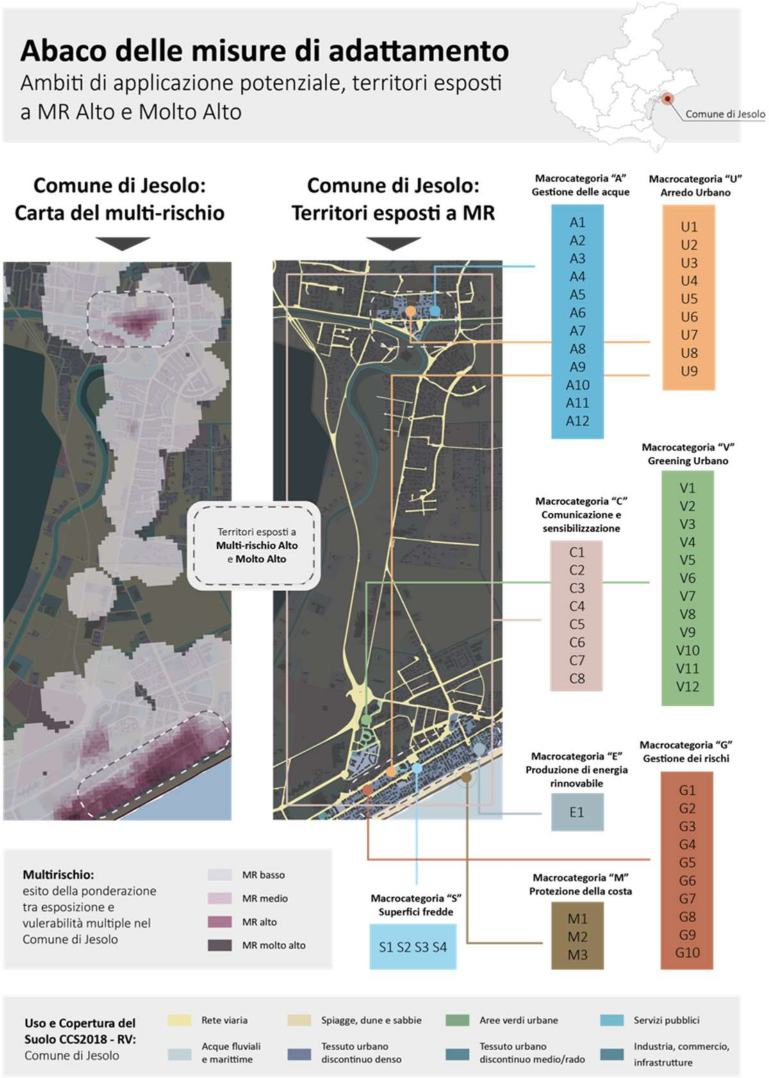

*Figure 21. The image shows a proposed classification. The two central urban areas, exposed to High and Very High multi-hazard, are related to the measures of the Abacus, divided by Macrocategories, bearing in mind the characterization of the underlying urban fabric.*

From the point of view of process fluidity, the use of a typological catalog of measures, from which one can learn technical characteristics and potential developments, is an important catalyst for the planning of activities. The abacus is divided into sections, defined as Macrocategories, within which are enclosed those measures which, if carefully designed down to the execution scale, can respond more effectively than others to the issues raised by the impacts identified by the Adriaclim model.

The following is a brief list of the typological categories of the measures referred to in the design of the model (for a more complete and exhaustive reading of the package, especially in relation to the link with land use and land cover types, please refer to the summary annex - Abacus of Measures):

- "U" - Punctual micro-interventions on street furniture: this category contains measures that act directly on the re-design or addition of elements to the urban context, with the aim of aesthetically and functionally upgrading built-up areas and public places. This category includes pavement resurfacing, upgrading of urban infrastructures, planters, public parks, and roofing elements (shelters, canopies, arcades, etc.).
- "C' - Communication and Awareness-raising: promoting a lasting and robust climate transition requires adequate collective technical and operational awareness and preparedness. Approaching the issues also from the point of view of technical and didactic awareness-raising of administrators, decision-makers, and citizens and defining communication systems for real-time and post-emergency forecasting is indispensable to involve as many stakeholders as possible and to achieve higher effectiveness and efficiency of interventions. This category contains measures that involve, inform, stimulate, and broaden the knowledge and interest of local communities.
- "G" - Risk management: climate change also leads to an increase - not always predictable either by their characterization or their intensity - of events that put territorial systems and people at risk. It is therefore necessary to increase the resilience of people, cities, and territories to increase their capacity to respond to multiple and unexpected risks. This macro-category, therefore, contains both measures that physically increase resilience capacities and measures that increase technical and emergency preparedness capacities among the population and specialized personnel (civil protection, decision-makers, technicians, volunteers, etc.).
- "A" - Water management: the management, especially during extreme or prolonged meteorological events, of water - whether meteoric, flowing down rivers or coming in from the sea - is one of the central issues in territorial security, particularly in urban or heavily man-made, and therefore sealed, areas. Intervention strategies fall into three possible options: stemming water flows, delaying and slowing their path to the final receptor - be it the sewer, the river, the sea, a ditch, etc. - and reusing the water resource. - and reuse the water resource. This macro-category contains measures that can be implemented to improve water management systems and to prepare territories and cities to reduce the chances of suffering devastating impacts in the event of weather events.
- "V" - Urban Greening: the term greening is related to the instrument implemented to support the agricultural policies of the European Union, which promotes greening initiatives to ensure the conservation of agricultural productivity in the long term with ecological practices. In the urban context, it is applicable in any intervention that reinforces, protects, and increases the green endowment with new trees, parks, SuDS, and lawns, to increase urban biodiversity, improve the

microclimate, increase the capacity to react to phenomena such as flooding, mitigate the effect of heat islands.

- "E" - Renewable energy production: If, as seen, it is indispensable to strengthen urban systems to better prepare them for the impacts of climate change, in parallel it is indispensable to strengthen as much as possible interventions for the mitigation, reduction, retention, compensation of CO2 produced, reduction of pollutants, etc. This category, therefore, includes interventions that contribute to increasing the share of renewable energy produced.
- "M" - Coastal protection: in the territory considered by this Annex, coastal systems are among those most at risk of suffering continuous and irreparable impacts such as storm surges, tornadoes, and extreme weather events. The measures contained in this macro-category, therefore, indicate some of the options that can be implemented to strengthen and make more resilient, both with engineering and grey interventions and with measures to strengthen the capacity of natural systems, the coastal strip, and the first marine strip.
- "S" - Cool Surfaces: this category contains interventions involving a different coloring of materials, either by replacement or by painting existing surfaces. These interventions have the primary purpose of increasing albedo, but they are also very useful for improving the aesthetic quality of public spaces, car parks, shed roofs, etc. Moreover, due to their cost-effectiveness and speed of implementation, they can also be used for tactical urban planning and/or urban redevelopment.

## The analysis phase of the spatial government structure and mapping of existing plans

The mapping of plans makes it possible to verify the existence and consistency of local action with the objectives of super-ordinate bodies, to implement that vertical mainstreaming that facilitates synergies between bodies of different scales and supports smaller local authorities, which can refer to guidelines established at the regional level, as a basis for drawing up their own. As mentioned above, thanks to the principle of subsidiarity intrinsically contained in the hierarchies of territorial government, municipal planning instruments are already divided into voluntary or mandatory, strategic or implementation instruments that, when analyzed in depth, often already contain adaptation and mitigation actions. Often, contiguous municipalities are also equipped with different voluntary instruments: Urban Plan for Sustainable Mobility (PUMS), Sustainable Energy Action Plan (SEAP) - Sustainable Energy and Climate Action Plan (PAESC), Lighting Plan for the Containment of Light Pollution (PICIL), etc.

This reconnaissance will also have the utility of creating an initial phase of stakeholder involvement and empowerment of each sector in spreading awareness of climate change and of the actions that municipalities and their sectors can implement to contain risk and vulnerability.

## Definition of adaptation goals within a participatory process

Once the cognitive framework has been elaborated, the stakeholder involvement process has been defined and a participation process has been initiated, the already existing competencies and actions have been mapped, and the plans that can undergo a mainstreaming process have been drawn up, the time has come to define the *vision* around which the mainstreaming process can be built according to the objectives that are to be achieved. Indeed, a *vision* is a process through which a community defines the future it desires. Through public involvement, communities identify their purpose, core values, and vision of the future to be articulated by achieving their goals.

The development of adaptation goals consists of several logical steps, including, in a nutshell:

- an understanding of the general purposes of adaptation, including the need to act in accordance with the principles of effectiveness and efficiency by targeting public resources;
- the definition of an overall vision for the development of the territory under conditions of climate change;
- the identification of general adaptation goals, often derived from strategic indications of superordinate bodies (European, national, regional) and their territorialization into specific goals for local conditions;
- the proposal of possible options to achieve the objectives.

## Integration of adaptation actions into plans and programs at the local and territorial level

Having mapped the existing actions and also defined the objectives, there are, at this point, two possible situations, as exemplified:

1. if there are no adaptation actions in the individual municipalities, the variant may provide:
   - the modification of actions in the plans by adopting an adaptive approach;
   - or the inclusion of new adaptation actions.

2. in individual municipalities, there are already adaptation actions in existing plans. In this case, variants may provide for:
   - the updating of the actions in the plans by adopting an adaptive perspective, acting on the system's responsiveness;
   - the inclusion of new adaptation actions, if the survey shows that the existing ones are insufficient in quality and quantity, or the authority wishes to make a further commitment to the issue, recognizing its importance;

Having carried out this initial check and possibly one of these choices, the entity, also based on the knowledge framework constructed, the *vision,* and the objectives defined, may:

1. work on existing plans, as mentioned:
   - modifying existing actions with an adaptive perspective;
   - inserting new adaptation actions;

2. have a specific adaptation policy framework, as we shall see later.

In either case, the preferable choice is for authorities to take adaptation actions in a coordinated manner, if possible, according to a certain level of coherence. This would help the homogeneity of action by municipalities, but also increase the chances of, for example, receiving funds, participating in calls for tenders and funding, and the homogeneous development of the territory.

## Cyclical monitoring of factors exposed to multi-risk

The impacts of climate change, due to their inherent uncertainty, are constantly evolving in terms of their magnitude, location, and intensity on different territories, but above all, due to their unpredictable temporal variability.

It is for these reasons that the adaptation process will have to be cyclical, involving moments of verification and monitoring of results, stakeholder involvement, analysis of the effectiveness of the actions implemented, verification of the progress of the objectives, and, if necessary, modification of existing objectives and actions to make them more effective under the new conditions, defining new strategies and interventions.

The importance of stable involvement of the widest number (and type) of territorial stakeholders at an early stage of the process will be crucial to help periodically check the status of the implementation of the initiatives introduced.

Therefore, a periodic and circular process of verification of objectives and actions is defined in advance and, if they are outdated, achieved, or no longer relevant, new ones are proposed from the various sectors of the administrations involved or from stakeholders in the area.

This sharing process must be also undertaken between the technical and political apparatus, thus ensuring constant dialogue and integration of actions between sectors and administrative levels.

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## Glossary

**Adaptation:** the process of adapting to an external stimulus, in this case, climate change. In anthropic systems, adaptation to climate change describes the modification of habitation, production and behaviour to reduce the risks associated with this phenomenon.

**Adaptive capacity:** capacity of a system, institution, or organism, to respond to stresses by transforming itself in order not to lose its main characteristics when faced with a perturbation of its state. Concerning climate change, it is the capacity to evolve to reduce the negative impacts of climatic perturbations.

**Exposure:** the factor that makes up the risk equation. It represents the social and economic value attributed to a system. The value is established to the presence of people, livelihoods and structures, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social or cultural assets in places that are exposed to the event whose risk is to be considered.

**Extreme weather event:** an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

**Sea storm flooding (Ss):** phenomenon concerning the flooding of an area by a mass of water. It may be a natural phenomenon resulting from flooding due to the combined action of high tides and typhoons/tides in coastal areas, or the arrival of a tsunami on the coast.

**Mitigation:** about climate change, this refers to the intervention (or series of interventions) to reduce the anthropogenic impact on climate. For example, reducing climate-altering emissions, or increasing the capacity to absorb them.

**Multi-impact:** negative effect resulting from a convergence of weather and climate events on natural and anthropogenic systems. It may be expressed in terms of damage to health, the economy, relationships, goods, services, physical structures (e.g. buildings) and infrastructure.

**Danger (hazard):** an event that may hurt a given territory or system. Hazard is associated with the origin of a risk, e.g. a heat wave, intense precipitation, or storm.

**Hazard:** the factor that makes up the definition of risk. The probability that a given phenomenon will occur with a certain intensity in a given period, in a given area. Hazardousness describes, for example, the likelihood of the occurrence of an extreme event.

**Resilience:** The ability of a system to cope elastically with disturbances, i.e. to return to the state before the disturbance.

**Risk:** Probability that a certain event will occur with the severity of its consequences. It is generally determined as a function of hazard, vulnerability and exposure. It is often associated with the type of event: e.g. seismic risk, flood risk, health risk.

**Multi-risk (MR):** susceptibility to multi-hazard. The definition of 'multi-risk susceptibility' considers the propensity of a territorial system to suffer potential damage expected following the occurrence of a particular extreme climatic event. It is important to remember that in this morphological analysis test, climate event-related hazard is treated and evaluated concerning the type of impact and its potential relationship with urban design.

**Multi-vulnerability (MV):** a spatial learning model for the assessment of cumulative impacts (UHI, Urban flooding and Sea storm) quantified on the basis of the physical-morphological structure of the territories under investigation. The cumulative impact is defined by the combination of several spatial variables (land use, land cover, settlement patterns, density, etc.), standardised and weighted using a multi-criteria evaluation technique.

**Stakeholder engagement:** a model for the integrated recognition of spatial priorities for climate adaptation. It is a tool that can feed into participatory working tables with the aim of actively involving different economic stakeholders and technical competences in the construction of a shared and multi-functional adaptation process.

**Multi-criteria spatial assessment:** Multi-criteria climate impact assessment to support models of adaptation-oriented local governance models,

**Vulnerability:** A factor that makes up the definition of risk. The vulnerability of an element (people, buildings, infrastructure, economic activities) and the propensity to suffer damage as a result of the stresses induced by an event.

**UHI:** Extreme weather condition, characterised by high temperatures, above the usual values, which may last for days or weeks.

**Urban flooding (UF):** modelling (%) of surface stormwater runoff on the basis of a spatial association between land uses and landforms assessed on a catchment scale.