CLIMAAX
climate ready regions

Deliverable Phase 2 – Climate risk assessment

Heat-wave risk analysis & adaptation for vulnerable groups

(LUGIA)

Spain/Huércal-Overa

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Document Information

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Table of contents

Document Information 2
Table of contents 3
List of figures 4
List of tables 4
Abbreviations and acronyms 6
Executive summary 7
1. Introduction 9
1.1 Background 9
1.2 Main objectives of the project 9
1.3 Project team 10
1.4 Outline of the document's structure 10
2 Climate risk assessment – phase 2 11
2.1 Scoping 11
2.1.1 Objectives 11
2.1.2 Context 12
2.1.3 Participation and risk ownership 13
2.1.4 Application of principles 14
2.1.5 Stakeholder engagement 15
2.2 Risk Exploration 17
2.2.1. Screen risks (selection of main hazards) 17
2.2.2 Choose Scenario 18
2.3 Regionalized Risk Analysis 19
2.3.1. Extreme heat and heatwaves - fine-tuning to local context 19
2.4 Key Risk Assessment Findings 34
2.4.1 Mode of engagement for participation 34
2.4.2 Gather output from Risk Analysis step 34
2.4.3 Assess Severity 35
2.4.4 Assess Urgency 36
2.4.5 Understand Resilience Capacity 37
2.4.6 Decide on Risk Priority 37
2.5 Monitoring and Evaluation 38

2.6 Work plan Phase 3 39
3 Conclusions Phase 2- Climate risk assessment 41
3.1. Strategic conclusions 41
3.2. Operational conclusions for adaptation 41
3.3. Implementation conclusions 42
3.4. Methodological conclusions and remaining challenges 42
4 Progress evaluation 43
5 Supporting documentation 45
6 References 47

List of figures

Figure 2-1. Stakeholder governance structure, risk ownership, and responsibilities in the LUGIA project in Huércal-Overa. Source: Self-produced 13
Figure 2-2. Thermal exposure map presented for discussion and validation during the technical stakeholder session with municipal representatives. Source: LUGIA Phase 2 technical presentation, 2 June 2026. 15
Figure 2-3. Spatial distribution and intensity of participatory heat-map contributions in the main urban centre of Huércal-Overa. Source: Self-produced based on data collected through the LUGIA participatory mapping process. 17
Figure 2-4. Environmental Heat Risk Index in the main urban centre of Huércal-Overa. Source: LST, solar exposure and tree canopy. Self-produced using data layers detailed in chapter 2.3.1.3.1 - 01_Environmental_Heat_Risk_Index_Workflow.ipynb 28
Figure 2-5. Population Vulnerability Index by census section in Huércal-Overa. Source: INE age, income, and education data. Source: Self-produced using data layers detailed in chapter 2.3.1.4.1. - 02_Population_Vulnerability_Index_Workflow.ipynb 30
Figure 2-6. Socio-environmental Heat Risk Index in the main urban centre of Huércal-Overa. Source: Environmental Heat Risk Index and Population Vulnerability Index. Source: Self-produced using data layers detailed in chapter 2.3.1.5.1. - 03_Socioenvironmental_Heat_Risk_Index_Workflow.ipynb 33

List of tables

Table 2-1. Monthly distribution of stakeholder survey responses during Phase 2. Source: Self-produced from Google Forms survey data. 16
Table 2-2. Climate scenarios and projected changes in heatwave exposure considered in the Phase 2 assessment. Source: Phase 1 LUGIA climate-risk assessment. 19
Table 2-3. Data overview for local fine-tuning of extreme heat and solar-exposure assessment. 21
Table 2-4. Data overview for local fine-tuning of environmental heat-regulation capacity 21
Table 2-5. Data overview for environmental and socio-environmental heat-risk assessment 22
Table 2-6. Input layers of the Environmental Heat Risk Index workflow 26
Table 2-7. Input layers of the Population Vulnerability workflow 29

Table 2-8. Input layers of the Socio Environmental Risk Index workflow 31
Table 2-9. Evaluation dashboard for extreme-heat risk in Huércal-Overa. 37
Table 4-1. Overview of key performance indicators 43
Table 4-2. Overview of milestones 44

Abbreviations and acronyms

Abbreviation / acronym	Description
AEMET	Spanish State Meteorological Agency
AI	Artificial Intelligence
CLIMAAX	Climate Risk and Vulnerability Assessment Framework and Toolbox
CMIP6	Coupled Model Intercomparison Project Phase 6
CO_2	Carbon dioxide
CORDEX	Coordinated Regional Climate Downscaling Experiment
CUSEC	Census section code
DBH	Diameter at Breast Height
EHRI	Environmental Heat Risk Index
EPSG	European Petroleum Survey Group
ETRS89	European Terrestrial Reference System 1989
EU	European Union
GIS	Geographic Information System
INE	Spanish National Statistics Institute
LAI	Leaf Area Index
LST	Land Surface Temperature
LUGIA	Heat-wave Risk Analysis and Adaptation for Vulnerable Groups
NBS	Nature-based Solutions
NDVI	Normalised Difference Vegetation Index
PGOU	General Urban Development Plan
PNOA	Spanish National Aerial Orthophotography Plan
PVI	Population Vulnerability Index
QR	Quick Response
RCP	Representative Concentration Pathway
SAC	Special Area of Conservation
SAVI	Soil-Adjusted Vegetation Index
SUDS	Sustainable Urban Drainage Systems
UGI	Urban Green Infrastructure
UMEP	Urban Multi-scale Environmental Predictor
UTM	Universal Transverse Mercator
UVA	Ultraviolet A radiation
UVB	Ultraviolet B radiation

Executive summary

Purpose and scope

This deliverable was developed to address the increasing risk posed by extreme heat and recurrent heatwaves in Huércal-Overa and the need for more precise local evidence to guide adaptation. Building on the climate projections and hazard assessment completed in Phase 1, Phase 2 identifies where heat exposure is concentrated, which environmental and social factors explain the resulting risk, and which districts, settlements and public spaces should be prioritised.

A central issue addressed by the assessment is that the hottest areas do not necessarily coincide with the areas of greatest climate risk. Risk also depends on shade, tree-canopy coverage, vegetation condition, pavement characteristics, population sensitivity, and adaptive capacity. The reader will learn how these factors interact across the municipality, what the main current and future risk levels are, and how the results support the adaptation measures planned for Phase 3.

Assessment framework, participation, and scenarios

The original focus on extreme heat and heatwaves remained unchanged, but the scope was refined to include LST, solar exposure, shade, pavements, Urban Green Infrastructure, vegetation condition and resilience, ecosystem services, and population vulnerability. The analysis covered the municipality, the main urban centre, seven urban districts, six principal settlements, census sections, regular grids, green spaces, and individual vegetation elements.

Stakeholder engagement included a technical meeting with municipal representatives, direct contact with local organisations, an online survey, a participatory heat map and communication through different channels. The map recorded 55 georeferenced contributions, helping to identify exposed streets, healthcare and educational environments, pedestrian routes, highly paved public spaces, vulnerable groups, and local hotspots not fully represented in the spatial datasets.

The scenario framework established in Phase 1 was retained, using RCP 4.5 and RCP 8.5 to represent intermediate and high-emission futures and the periods 2016–2045 and 2046–2075 for short-, medium- and long-term interpretation. Phase 2 used the Phase 1 results to assess how current exposure and vulnerability may lead to more severe impacts under increasing heat.

Regionalized risk analysis

Weekly Landsat 8 Land Surface Temperature data from June to September 2025 identified persistent summer thermal patterns, with the highest values in July and August. High temperatures were associated with dry agricultural land, exposed soils, mobility areas, and prolonged solar exposure, while green areas and some residential and public-facility environments showed more moderate conditions.

Shade modelling indicated that 77.4% of the assessed area had high or very high total shade, although much of it was produced by buildings and does not provide the same cooling benefits as tree shade. Significant exposure remains in open streets, squares, pedestrian routes, and mobility areas. The pavement inventory covered 429,629.48 m², of which 87.32% was asphalt. Two field campaigns analysed 34 samples, with reflectance values between 10.6% and 49.5%. Asphalt and asphalt-cement surfaces averaged 19.0% reflectance and 81.0% absorptance, confirming the prevalence of dark, heat-absorbing materials.

The Urban Green Infrastructure assessment identified 5,696 woody vegetation elements belonging to 93 species in the main urban area. Inventoried green coverage represented 108,025 m² (5.14%), with a further 38.65 ha of complementary green cover identified through NDVI-SAVI analysis. The ecosystem-service assessment estimated 378,909.67 m² of potential shade, 1,026,158.29 m² of total leaf area and annual CO_2 absorption of 512.34 tonnes. Green spaces showed a small overall cooling effect, with local differences of up to about 0.37 °C in some larger or more continuous spaces. The resilience analysis classified approximately 40% of the tree population as moderately to highly resilient, 35% with intermediate vulnerability and 25% with severe or critical vulnerability under the extreme scenario.

The Environmental Heat Risk Index identified District 4 and Las Labores as high environmental-risk areas, while Districts 3 and 7 were low and Districts 1, 2, 5 and 6 were moderate. After incorporating age, income and education through the Population Vulnerability Index, District 4 remained the only urban district with high socio-environmental risk; Districts 1, 2 and 5 were medium, and Districts 3, 6 and 7 low. District 1 had the highest urban population vulnerability and rose from fifth to second in the combined ranking. All six principal settlements were classified as high socio-environmental risk, with Las Labores standing out because both environmental and social conditions were unfavourable.

Key Risk Assessment findings

Current extreme-heat severity was classified as substantial. Future severity remains substantial under the intermediate scenario and becomes critical under the high-emission scenario. By around 2060, annual heatwave days are projected to increase from approximately 10 historically to more than 15 under RCP 4.5 and more than 20 under RCP 8.5, with the most severe years potentially exceeding 30–40 days. Average duration may increase from less than 3 days to 6 days, while frequency may rise from approximately two to around four events per year, with more than six or seven events possible in extreme years.

Urgency was assessed as more action needed at municipal level, with immediate action required in priority locations and for long-lead measures. Resilience capacity was classified as medium, reflecting existing institutions, public services, warning mechanisms, technical knowledge, and Green Infrastructure, alongside significant financial, physical, natural, social and coordination limitations. Extreme heat was therefore assigned a high overall risk priority.

Conclusions and Phase 3

The main conclusion is that heat exposure and climate risk do not always coincide. The areas with the highest temperatures are not necessarily those where potential impacts are greatest, because risk also depends on effective shade, canopy continuity, vegetation resilience, pavement characteristics, social vulnerability, and public-space use. Environmental and socio-environmental risk maps should therefore be used together.

Phase 2 established a detailed territorial diagnosis, reproducible indicators and a baseline for municipal planning and monitoring. Remaining limitations include gaps in local health, housing, indoor-temperature, energy-poverty, outdoor-worker, and public-space-use data, together with the need for further field validation and broader participation in smaller settlements. Phase 3 will translate these results into an Urban Naturalization Strategy and digital platform, defining locally adapted guidelines, priority areas, NBS, climate-resilient vegetation and a phased implementation pathway.

1. Introduction

1.1 Background

Huércal-Overa is a municipality located in the province of Almería, Andalusia, in southeastern Spain. It covers an area of 318 km² and has a population of approximately 20,500 inhabitants, most of whom live in the main urban centre. The town lies within the Levante Almeriense region, between the Estancias and Almagro Mountain ranges, and is crossed by the Almanzora River.

The territory is characterised by a semi-arid Mediterranean climate, with hot, dry summers, mild winters, and highly irregular rainfall. Natural vegetation is scarce and dominated by scrublands and grasslands, while agriculture (almonds, citrus, vegetables, and intensive pig farming) plays a central role in the local economy. The Almanzora River crosses the municipality, although water resources are limited and irregular, which adds further stress to agricultural production. Land use is dominated by crops (about 46% of the territory) and scrub-grasslands (about 37%), while forest cover is minimal, reflecting the fragile ecological balance of the area. In addition, parts of the municipality are included within the Natura 2000 Network as Special Areas of Conservation (SAC), such as the Sierra de Almagro and surrounding habitats, which highlight its ecological importance despite limited forest cover.

Socio-demographically, Huércal-Overa presents a younger profile compared to regional averages, but the proportion of elderly residents is increasing. Around 20% of the population is of foreign origin, adding to the community's diversity. Despite this, unemployment remains above the national average, influencing the municipality's overall vulnerability. The municipality has experienced moderate growth in recent years, supported by migration, with the proportion of people over 65 continuing to rise (currently around 12%). This trend, combined with a younger-than-average structure, generates specific challenges for social services and increases sensitivity to extreme heat events.

Huércal-Overa's economy is strongly linked to agriculture and livestock, particularly almond and citrus cultivation, and intensive pig farming, which rank among the most important in Spain. The municipality also plays a role as a service hub for the surrounding rural areas, with health, education, and commercial activities concentrated in the main town. Average gross income remains below the national average, while unemployment levels are higher, reinforcing its socioeconomic vulnerability.

1.2 Main objectives of the project

The overall objective of the LUGIA project is to improve understanding of heat-related climate risk in Huércal-Overa and to provide the municipality with a robust evidence base for planning and implementing climate adaptation measures.

Phase 2 represents the transition from the general climate risk assessment developed in Phase 1 to a more detailed and locally focused analysis. Its purpose is to understand how urban form, environmental conditions, green infrastructure, and social vulnerability influence the distribution and potential impacts of extreme heat across the municipality. This local perspective is essential for identifying priority areas, supporting municipal decision-making, and preparing the Urban Naturalisation Strategy to be developed in Phase 3.

The CLIMAAX Handbook provided the methodological basis for the climate risk assessment conducted during Phase 1, helping to structure the analysis of hazard, exposure, and vulnerability

(CLIMAAX, 2026). Phase 2 built on this foundation by incorporating local datasets, high-resolution spatial information, and specific analytical models. These included land surface temperature data, digital surface and terrain models, high-resolution satellite imagery, an AI-based vegetation inventory, field measurements of pavement properties, socio-economic indicators, and participatory information.

The integration of these local sources increased the spatial detail, practical relevance, and applicability of the assessment, making it possible to move from a general diagnosis of heat risk to an operational understanding of where and why adaptation measures are most needed.

1.3 Project team

Team from Huércal-Overa Municipality

- **Baltasar Sánchez Pérez**: Political scientist and specialist in public administration, education, procurement, European projects, grants, and youth policies.
- **Alfonso Juan Cueli Bernal**: Agricultural engineer with 27 years of experience in local development, funding programmes, employment, trade, transport, and rural development.

Team from CESYT

- **Juan Bautista Tomás Gabarrón**: Telecommunications engineer (PhD) and co-founder of CanopyQ, specialising in AI and satellite technologies for urban green infrastructure.
- **Almudena Sánchez Centeno**: Environmental scientist specialising in urban green infrastructure, biodiversity, ecosystem services, and nature-based solutions for climate adaptation.
- **Antonio Ayllón Bermejo**: Computer scientist specialising in deep learning, computer vision, cloud architectures, satellite imagery, and geospatial data processing.
- **Pablo Lorenzo Domínguez:** Biologist specialising in GIS and remote sensing for biodiversity, ecosystem services, and climate adaptation assessments.
- **Laura Gómez Mendoza**: Biologist and urban arboriculture specialist with expertise in urban trees, biodiversity, environmental assessment, and GIS analysis.

Together, the team combines municipal management expertise with advanced environmental, geospatial, and technological capabilities.

1.4 Outline of the document's structure

The document is organized to guide the reader from the project context and methodological framework to the detailed risk assessment, its main conclusions, and the next steps. Following the Executive Summary and Introduction, Section 2 presents the Phase 2 Climate Risk Assessment, including the refined scope, stakeholder participation and risk ownership, risk exploration and scenario framework, regionalized analysis of extreme heat, Key Risk Assessment findings, Monitoring and Evaluation, and the Phase 3 work plan. Section 3 summarizes the main conclusions and remaining challenges, Section 4 evaluates progress against the project's key performance indicators and milestones, and Section 5 lists the supporting outputs and datasets produced. The document concludes with the references.

2 Climate risk assessment – phase 2

2.1 Scoping

The scoping established in Phase 1 remained valid, with extreme heat and heatwaves as the main climate risk. Phase 2 refined the assessment by incorporating more detailed local environmental, urban, and social factors and by working across multiple spatial scales. Stakeholder engagement was also strengthened through municipal and citizen participation.

2.1.1 Objectives

The objective of the Climate Risk Assessment is to improve understanding of how extreme heat affects Huércal-Overa and how risk varies across the municipality. Phase 2 refines the Phase 1 assessment through a more detailed analysis of the urban, environmental, and social factors influencing exposure, vulnerability, and adaptive capacity.

The specific objectives were to:

- analyse the relationship between Land Surface Temperature and the municipality's physical and functional characteristics.
- assess the distribution, coverage, condition, resilience, and thermal-regulation capacity of Urban Green Infrastructure.
- identify areas with limited shade and high solar exposure.
- examine the characteristics and potential thermal contribution of the main urban pavement types.
- broaden the assessment of social vulnerability by incorporating demographic, economic and educational variables.
- incorporate local knowledge and citizens' perceptions.
- integrate environmental, social, and participatory evidence to identify priority areas for adaptation.

The expected outcome is an integrated evidence base identifying the districts, settlements, and public spaces where unfavourable thermal conditions coincide with limited shade, low tree-canopy coverage, or greater social vulnerability. The assessment also explains the main drivers of risk in each area, recognising that similar final risk levels may result from different combinations of temperature, solar exposure, urban form, vegetation, and socioeconomic conditions.

The assessment provides criteria for prioritising interventions, allocating resources and designing locally adapted measures. Its results will directly inform the Phase 3 Urban Naturalisation Strategy and support municipal climate-adaptation, urban-planning, public-space, Green Infrastructure, mobility, public-health, and investment decisions, while also providing local evidence for regional climate-adaptation and territorial-planning frameworks.

The assessment is subject to methodological and practical limitations. LST does not directly represent air temperature or human thermal comfort, while the shade model estimates total physical shade without fully distinguishing its source or pedestrian benefits. Vegetation inventories and ecosystem-service estimates rely partly on remote sensing, artificial intelligence and allometric models, introducing uncertainty related to image resolution, canopy overlap, species identification, and model assumptions. Social data were only consistently available at census-section level, excluding variables such as health status, housing quality, access to air conditioning, social

isolation, and proximity to healthcare services. Stakeholder participation was uneven, particularly in smaller settlements; pavement analysis used a limited number of field samples; and vegetation resilience was assessed through comparative models rather than long-term physiological monitoring.

These bottlenecks were addressed by combining complementary datasets, working at multiple spatial scales, contrasting technical results with local knowledge, documenting assumptions and uncertainty, and interpreting the outputs as relative indicators for territorial comparison and prioritisation rather than as absolute predictions.

2.1.2 Context

Until the development of LUGIA, climate hazards, impacts and risks in Huércal-Overa were assessed through regional studies and national platforms such as AEMET and AdapteCCa (AEMET, Nd; AdapteCCa, Nd). These sources provided valuable information on historical and projected climate trends, drought indicators, and climate scenarios, but their spatial resolution was insufficient to analyse differences in heat exposure and vulnerability within the municipality.

Phase 1 addressed this limitation by analysing the historical and projected evolution of heatwaves and producing an initial assessment of exposure and population vulnerability (Municipality of Huércal-Overa and CESYT, 2025). Phase 2 builds on this baseline with higher-resolution local information on land use, urban form, vegetation, shade, pavements, social vulnerability, and stakeholder perceptions, allowing a more detailed understanding of how extreme-heat risk is generated and distributed locally.

Heat risk in Huércal-Overa results from the interaction between increasing extreme heat, the municipality's semi-arid climate, impermeable surfaces, limited shade, uneven vegetation cover, and the spatial concentration of vulnerable groups. This forms part of a wider Mediterranean context of rising temperatures, aridity, drought, water scarcity, with implications for public health, Urban Green Infrastructure, water management, agriculture, livestock farming, mobility, and public-space use.

The governance framework includes European, national, regional and local climate and planning instruments, including the European Green Deal and EU Climate Adaptation Strategy (European Commission, 2019, 2021), Spain's National Climate Change Adaptation Plan (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021), the Andalusian Climate Action Plan (Junta de Andalucía, 2021), and the local PGOU and Huércal-Overa 2030 Agenda (Municipality of Huércal-Overa, 2020, 2022). Phase 2 strengthens the evidence available to support municipal responsibilities in urban planning, public health, civil protection, green-area management, water management, and emergency response.

The most relevant sectors are public health, urban planning, Urban Green Infrastructure, water management, mobility, social services, agriculture, livestock farming, and public facilities. Extreme heat may increase health risks for vulnerable groups, reduce the usability of public spaces, increase cooling and irrigation demand, and intensify pressure on vegetation and water resources.

Adaptation interventions include increasing effective tree-canopy cover and shade, reinforcing Green Infrastructure connectivity, selecting species adapted to semi-arid conditions, reducing exposed impermeable surfaces, improving pavement permeability, introducing Sustainable Urban Drainage Systems, and installing artificial shade where planting is not feasible. Priority should be

given to highly exposed and intensively used locations such as pedestrian areas, school routes, healthcare environments, public squares, and streets with limited shade.

Beyond the municipal context, LUGIA is directly embedded in the wider CLIMAAX programme, which provides the common climate risk assessment framework, workflows and tools applied in the study. It also draws on Copernicus climate information and complements the Huércal-Overa 2030 Urban Agenda. No specific neighbouring initiative was directly incorporated into the assessment; however, wider regional pressures, particularly increasing aridity and water scarcity, influence both heat risk and the feasibility of adaptation measures.

2.1.3 Participation and risk ownership

Phase 2 built on the stakeholder mapping completed in Phase 1 and moved from identification to active consultation and integration of local knowledge. Engagement included a technical participatory session with municipal staff, direct contact with local organisations, an online survey, a participatory heat map and communication through municipal and project channels.

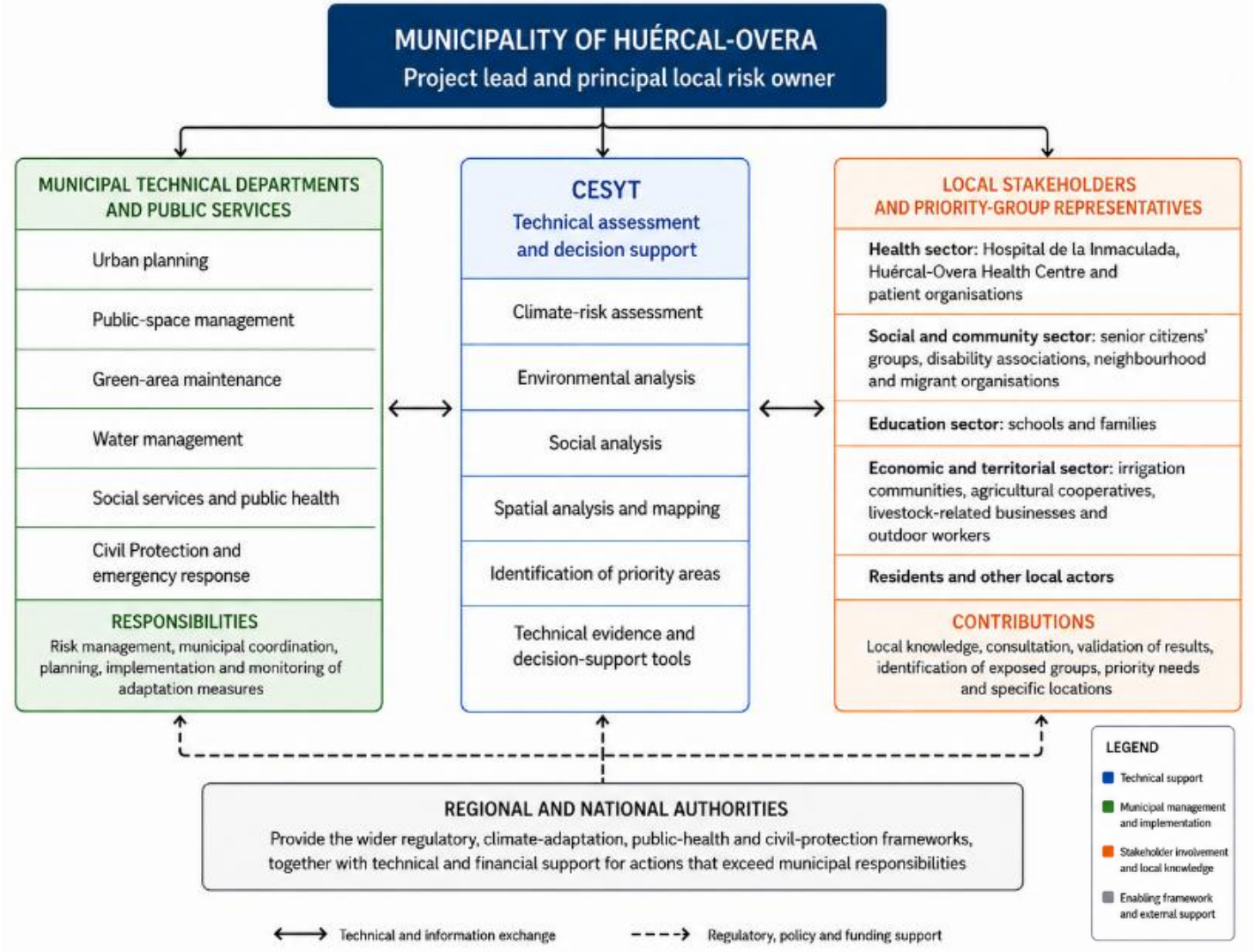


Figure 2-1. Stakeholder governance structure, risk ownership, and responsibilities in the LUGIA project in Huércal-Overa. Source: Self-produced

As shown in Figure 2-1, relevant stakeholders included the Municipality and its technical departments, Civil Protection, healthcare and educational services, associations representing

vulnerable groups, neighbourhood and migrant organisations, irrigation communities, agricultural cooperatives, and livestock-related businesses. Municipal representatives working in territorial management, urban planning and climate-related areas participated directly in the CLIMAAX technical meeting, while organisations and residents contributed through the consultation process.

Risk identification is shared among municipal departments, stakeholders, and citizens. CESYT leads the risk assessment with municipal staff, while mitigation and adaptation fall primarily to the Municipality and the departments responsible for urban planning, public spaces, green-area and water management, social services, public health, Civil Protection, and emergency response.

Priority groups include older people, young children, people with chronic illnesses or disabilities, low-income households, residents of poorly protected housing and outdoor workers. Relevant representatives include organisations for older people, patients and people with disabilities, schools and families, healthcare providers, neighbourhood and migrant associations and organisations linked to agriculture and other outdoor employment.

No official quantitative threshold for acceptable or tolerable heat risk was identified in Huércal-Overa. The project therefore applies a preventive approach, prioritising exposed vulnerable groups, essential facilities, and highly used public spaces. Phase 3 should broaden direct participation in smaller settlements and among groups represented only indirectly in Phase 2.

2.1.4 Application of principles

The CLIMAAX Framework principles (CLIMAAX, 2026) were integrated throughout Phase 2, influencing data selection, methodological design, interpretation of results and adaptation priorities.

Social justice, equity, and inclusivity were addressed by recognising that heat exposure, vulnerability and adaptive capacity are unevenly distributed across Huércal-Overa. The assessment incorporated age, income and education into the social vulnerability analysis and considered groups with greater sensitivity or lower adaptive capacity, including older people, young children, people with chronic illnesses or disabilities and low-income households. Local knowledge was incorporated through stakeholder engagement, while the more limited participation of smaller settlements and some vulnerable groups was explicitly recognised as a limitation to be addressed in Phase 3.

Quality, rigour, and transparency were supported through traceable data sources, documented assumptions, and reproducible analytical procedures. The three risk indices were implemented through dedicated Python workflows that allow the calculation process to be traced from the original input layers to the final mapped outputs. Spatial preprocessing was conducted in QGIS using a common coordinate reference system, while data sources, weighting criteria, processing steps, and uncertainties are documented in Section 2.3 and in the supporting documentation.

The precautionary approach was applied by avoiding delays in risk reduction solely because some information remained incomplete. Priority was given to locations where high thermal exposure coincides with greater social vulnerability, limited shade, insufficient vegetation, or sensitive facilities. No single indicator was used independently to determine adaptation priority; instead, decisions were based on the convergence of environmental, social, territorial, and participatory evidence. Where uncertainty remained, conclusions were expressed cautiously and linked to further data collection, field validation, and stakeholder engagement.

2.1.5 Stakeholder engagement

Stakeholder engagement during Phase 2 combined communication, consultation, and participation, building on the stakeholder mapping of Phase 1. The objective was to communicate intermediate results, incorporate local knowledge into the Climate Risk Assessment and identify priority locations, vulnerable groups and adaptation needs not fully captured by the technical analysis.

The process included an online technical session with municipal staff, direct contact with local associations and organisations, a digital survey, a participatory urban heat map and communication through the project microsite, One Pager, municipal channels, social media, and press releases.

The main CLIMAAX-related meeting was held online on 2 June 2026 with municipal representatives working in territorial management, urban planning and other areas linked to climate adaptation. The project team presented intermediate results on heatwave evolution, Land Surface Temperature, and preliminary thermal-exposure patterns, including the spatial analysis shown in Figure 2-2.

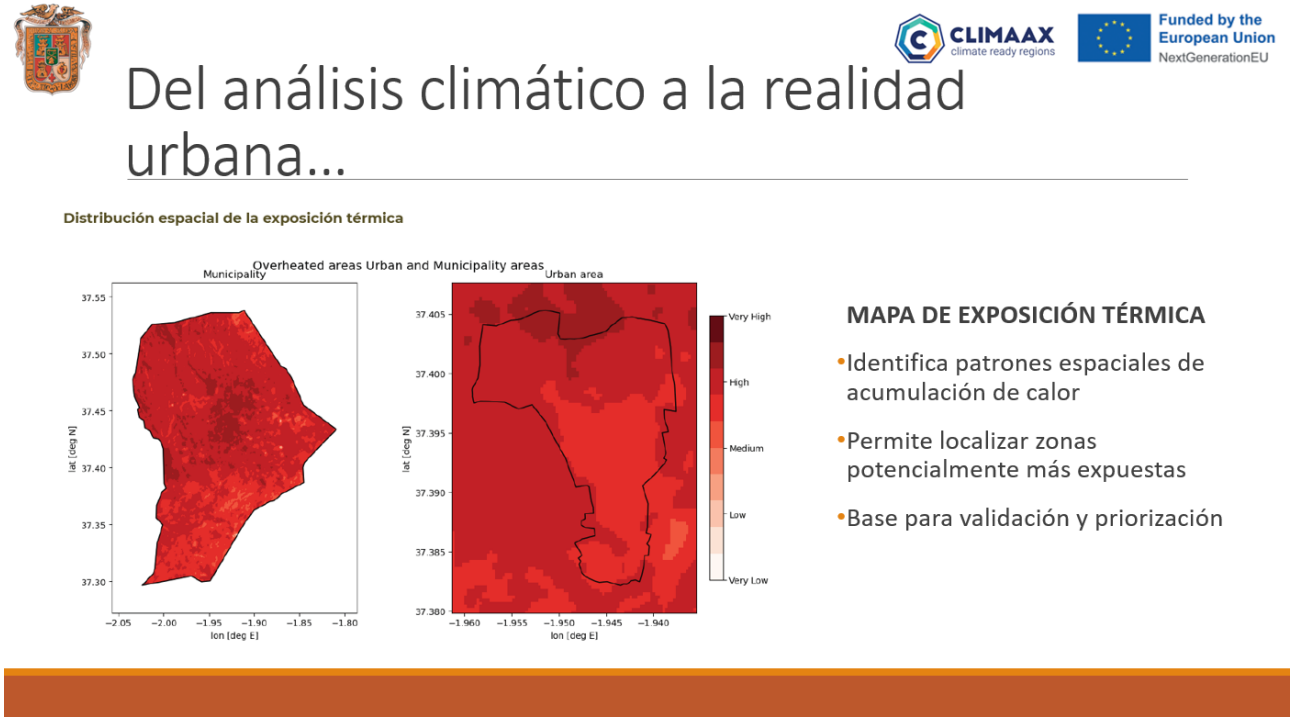


Figure 2-2. Thermal exposure map presented for discussion and validation during the technical stakeholder session with municipal representatives. Source: LUGIA Phase 2 technical presentation, 2 June 2026.

Municipal staff highlighted the thermal influence of agricultural and forest land-use changes, including the replacement of tree crops by herbaceous crops and the loss of forested areas around El Saltador and the Torre Vigía. They also identified more moderate temperatures in Las Labores, greater thermal discomfort in La Hoya and significant heat accumulation around the Hospital de la Inmaculada. Participants also expressed interest in Urban Green Infrastructure, new green spaces, Sustainable Urban Drainage Systems and Nature-based Solutions.

The project goals, intermediate results and participation opportunities were communicated through complementary technical and accessible formats. The microsite and One Pager explained the project and provided direct access to the survey and map through QR codes. Municipal channels and press coverage were used to present the project, share progress, publish calls for participation and raise awareness of heat risk and adaptation.

The broader engagement process involved residents, neighbourhood associations, older people's groups, social and health organisations, disability associations, schools, and other local actors. Associations were contacted by email and telephone to disseminate the survey and participatory map and encourage participation among heat-vulnerable groups. As the survey was voluntary and anonymous, responses could not always be linked to specific organisations or stakeholders.

The survey collected perceptions of temperature change, impacts on daily life, exposed locations, vegetation condition, vulnerable groups, and preferred adaptation measures. Participation was concentrated in June and July 2026, as shown in Table 2-1, with 59.4% of responses received in June and 33.3% in July.

Table 2-1. Monthly distribution of stakeholder survey responses during Phase 2. Source: Self-produced from Google Forms survey data.

Month	Total answers	Percentage
May 2026	5	7,2%
June 2026	41	59,4%
July 2026	23	33,3%

The results were positively received and broadly consistent with local experience. A total of 77.8% of respondents considered that summer heat had increased substantially or greatly. Extreme heat strongly affected daily life for 55.6% and had a considerable effect for a further 28.9%. In addition, 88.9% perceived clear differences in heat intensity between different parts of the municipality.

More than 90% identified streets without trees as the places where heat accumulates most strongly. Squares, school surroundings, car parks, and other highly paved spaces were also repeatedly mentioned. Older people, children, people with chronic illnesses and outdoor workers were identified as the most affected groups. Frequently cited locations included Plaza Mayor, Carretera de la Estación, the fairgrounds, the Hospital de la Inmaculada, Plaza de la Constitución, Noria del Pino, the Alameda and several school surroundings. The spatial distribution of these perceived heat hotspots is shown in Figure 2-3.

The participatory map recorded 55 georeferenced contributions, along the central axis of the main urban centre. The main concentrations occurred around Plaza Mayor, Carretera de la Estación, the Hospital de la Inmaculada and other frequently used public spaces with extensive paving, limited shade, and low vegetation cover.

The participatory findings showed a meaningful correspondence with the technical assessment. Contributions around the hospital coincided with District 4, the district classified as having high risk on both the environmental and the socio-environmental maps, while observations in the southern sector coincided with District 1, which records the highest population vulnerability in the urban centre. At the same time, contributions in districts classified as having moderate or low overall environmental risk identified specific streets and public spaces with significant local exposure. Participation therefore both confirmed the main spatial patterns and refined them at street and public-space scale.

Participant feedback emphasised vegetation loss, insufficient shade, exposed public spaces and the need to interpret district-level results alongside actual use and local knowledge. The engagement outcomes will be used in Phase 3 to prioritise public spaces, identify opportunity areas and refine adaptation measures. Municipal departments and local stakeholders will use the results to support Green Infrastructure, shading, public-space design, and climate-adaptation decisions,

while local knowledge will help ensure that proposals reflect the actual use and social relevance of each location.



Figure 2-3. Spatial distribution and intensity of participatory heat-map contributions in the main urban centre of Huércal-Overa. Source: Self-produced based on data collected through the LUGIA participatory mapping process.

Further Phase 3 meetings will refine adaptation proposals with municipal departments, vulnerable groups, local associations, and stakeholders from smaller settlements, while results will continue to be shared through existing municipal communication channels.

The main difficulties were uneven territorial participation, limited direct representation of some priority groups and the digital format. No participatory-map contributions were received from the smaller settlements, reflecting limited participation rather than an absence of heat-related problems. The consultation period also coincided with the Andalusian regional election period, which reduced the availability of some institutional and local actors, while the digital format may have limited participation among people with less access to or familiarity with online tools.

Phase 3 should therefore maintain existing communication channels while strengthening direct engagement in the smaller settlements and with vulnerable groups, moving from risk localisation and validation towards the discussion and refinement of specific adaptation proposals.

2.2 Risk Exploration

Phase 2 retained the risk framework established in Phase 1 and focused on refining the understanding of extreme heat at local scale.

2.2.1. Screen risks (selection of main hazards)

The Phase 1 hazard screening remained valid: extreme heat and recurrent heatwaves continued to be the central hazards assessed by LUGIA. Phase 2 did not add new hazards but refined the spatial

distribution of extreme-heat risk and its interaction with environmental and social vulnerability. Drought, wildfire, and intense rainfall remain relevant at regional level but were not assessed separately because the project focuses specifically on heat risk.

The main new development was the identification of local differences in thermal exposure and environmental heat-regulation capacity. Higher summer surface temperatures were associated with dry agricultural land, open and mobility areas, prolonged solar exposure, and limited vegetation, while green, recreational and some residential or public-facility areas showed more moderate conditions. Las Labores and La Hoya were the settlements with the highest average surface temperatures, whereas El Saltador and San Francisco showed more moderate conditions.

The most affected groups remain older people, children, people with chronic illnesses or disabilities, low-income households, and outdoor workers. Phase 2 refined the vulnerability assessment by incorporating income and education indicators and examining the location of schools, healthcare facilities, pedestrian routes and intensively used public spaces. Risk is highest where thermal exposure and solar radiation coincide with insufficient shade, limited vegetation and reduced social adaptive capacity.

The Copernicus Interactive Climate Atlas (Copernicus Climate Change Service, 2024) was explored for south-eastern Spain using CMIP6 and CORDEX-EUR-11 climate projections. Across increasing global warming levels, the clearest signal is a rise in daily maximum temperatures and in the number of extreme hot days above 35 °C. The Atlas also indicates longer dry periods and declining summer precipitation, although precipitation-related projections show greater uncertainty. As the CORDEX-EUR-11 projections have a spatial resolution of approximately 12.5 km, these findings were interpreted as regional climate context rather than as evidence of differences within Huércal-Overa. For the municipality, the combination of more frequent extreme-heat conditions and reduced water availability may simultaneously increase population exposure and constrain the capacity of vegetation to provide urban cooling.

Phase 2 expanded the evidence base through summer Landsat 8 Land Surface Temperature, land-use information, solar-exposure and shade modelling, pavement characteristics, high-resolution vegetation mapping, vegetation-condition and climate-resilience indicators, and an expanded social vulnerability assessment. This allowed a more precise identification of areas where high thermal exposure, limited environmental regulation and greater social vulnerability coincide.

Remaining information needs include spatially detailed data on heat-related morbidity, hospital admissions, and mortality; housing quality, indoor temperatures, energy poverty, daily mobility, and public-space use; and additional field measurements to validate shade, surface-temperature and pavement behaviour and monitor changes over time.

2.2.2 Choose Scenario

The scenario framework established in Phase 1 was retained for Phase 2. Two future climate pathways were considered: RCP 4.5, representing an intermediate-emission pathway, and RCP 8.5, representing a high-emission pathway. These scenarios were selected to represent contrasting plausible levels of future climate pressure and because Phase 1 showed clear differences between them in the projected evolution of heatwave frequency, duration, and cumulative exposure in Huércal-Overa. Under the local heatwave definition, the historical average of approximately 10 heatwave days per year was projected to increase to more than 15 days under RCP 4.5 and more than 20 days under RCP 8.5 by around 2060, while average event duration could increase from less

than 3 days to nearly 6 days and annual frequency from approximately two to around four events per year.

Phase 2 did not develop independent future socio-economic scenarios. Population growth, future economic activities, food consumption, and prices were therefore not projected quantitatively. Instead, current demographic and socioeconomic conditions were used as the reference baseline, including the spatial distribution of population and the age, income and educational variables incorporated into the Population Vulnerability Index. Current land use, vegetation, shade, pavements, and other local environmental conditions were likewise treated as the present-day territorial baseline.

Future climate and socio-economic conditions were therefore combined through a scenario-conditioned risk assessment. The climate projections produced in Phase 1 were used as the future hazard component, while the higher-resolution environmental and socioeconomic datasets developed in Phase 2 represented the current spatial distribution of exposure, mitigation capacity, and vulnerability. This approach makes it possible to assess how existing local risk factors could lead to different levels of impact as the heatwave hazard intensifies, while explicitly assuming that socio-economic and territorial conditions remain broadly unchanged.

The same time horizons defined in Phase 1 were retained: 2016–2045 and 2046–2075. The first horizon represents the short- to medium-term period considered in the original CLIMAAX assessment, while the second provides a longer-term perspective relevant for urban planning, Green Infrastructure development and vegetation resilience. The scenario-specific changes used as the future climate reference for Phase 2 are summarised in Table 2-2.

Table 2-2. Climate scenarios and projected changes in heatwave exposure considered in the Phase 2 assessment. Source: Phase 1 LUGIA climate-risk assessment.

Scenario	Period	Projected change in heatwave days	Risk implication
RCP 4.5	2016–2045	~+150%	Moderate increase in future heat risk
RCP 4.5	2046–2075	Up to ~+300% (most sensitive areas)	Medium-high risk; high in some urban areas
RCP 8.5	2016–2045	~+200%	Higher future heat risk
RCP 8.5	2046–2075	>+600% (much of the municipality)	High to very high risk in priority urban areas

These scenario-specific results were not recalculated in Phase 2 but were used as the future climate baseline for interpreting the locally refined environmental and socio-environmental risk patterns. In this way, Phase 2 refines the spatial understanding of risk by identifying which current characteristics of the territory may amplify or reduce the expected impacts.

2.3 Regionalized Risk Analysis

Phase 2 retained extreme heat and heatwaves as the main climate hazard, while refining the assessment through higher-resolution local data and a multiscale analysis of thermal exposure, urban form, materials, vegetation, and social vulnerability.

2.3.1. Extreme heat and heatwaves - fine-tuning to local context

Phase 2 fine-tuned the heat-hazard assessment by incorporating local thermal, urban, vegetation and socioeconomic factors. Shade, tree-canopy cover, pavements, and socioeconomic conditions were treated as drivers of exposure, heat-regulation capacity, and vulnerability.

2.3.1.1. Relationship with the Phase 1 CLIMAAX assessment

Phase 2 builds directly on the climate-risk assessment developed in Phase 1 using the CLIMAAX framework. The hazard definition, climate scenarios, future time horizons, and projected evolution of heatwaves established in Phase 1 were retained and were not recalculated. Phase 1 provided the regional climate signal and demonstrated that heatwave frequency, duration and cumulative exposure are expected to increase under both RCP 4.5 and RCP 8.5, with stronger changes under the high-emission pathway. It also produced the first spatial assessment of heat-related exposure and population vulnerability for Huércal-Overa.

The purpose of Phase 2 was therefore not to replace the CLIMAAX assessment, but to fine-tune it at local scale. The regional hazard identified in Phase 1 was combined with higher-resolution information describing the environmental and social conditions that determine how that hazard is expressed within the municipality. These additional datasets include Land Surface Temperature, land use, solar exposure and total shade, pavement properties, tree-canopy and integrated green cover, vegetation structure and physiological resilience, ecosystem-service provision, and socioeconomic vulnerability. Citizen and stakeholder information was also used to support the interpretation of local risk patterns.

This refinement is important because the same regional increase in heatwaves can produce different local impacts depending on heat accumulation and mitigation capacity. Highly absorptive pavements, limited canopy, and little shade can intensify impacts compared with shaded, vegetated areas, while similar environmental conditions may generate different risk levels depending on population sensitivity and adaptive capacity.

The integration of Phases 1 and 2 can be understood as a two-scale assessment: Phase 1 defines the evolution of the climate hazard and broad future-risk patterns, while Phase 2 identifies the local environmental and socioeconomic factors that amplify or reduce its impacts and provide the spatial detail needed for adaptation planning.

Three reproducible analytical workflows were developed to operationalise this local refinement:

- Workflow 1 – Environmental Heat Risk Index (EHRI): integrates normalised summer LST, tree-canopy deficit and total-shade deficit to identify areas where heat exposure coincides with limited environmental regulation capacity.
- Workflow 2 - Population Vulnerability Index (PVI): integrates age sensitivity, income vulnerability, and educational vulnerability to characterise differences in population sensitivity and adaptive capacity.
- Workflow 3 - Socio-environmental Heat Risk Index: combines the EHRI and PVI to identify where environmental risk coincides with greater social vulnerability.

These workflows do not reproduce the original CLIMAAX calculations; they use the Phase 1 assessment as the climate-risk baseline and extend it with finer-resolution local data. The climate hazard component comes from Phase 1, while exposure, mitigation capacity and vulnerability were fine-tuned in Phase 2 using local datasets and complementary analytical tools.

Phase 1 outputs carried into Phase 2 include heatwave projections for 2016–2045 and 2046–2075 under RCP 4.5 and RCP 8.5, together with scenario-specific future-risk results. These projections are not recalculated but used as the future climate reference for interpreting local environmental and socio-environmental risk and assessing future severity, urgency, and resilience in Section 2.4.

The calculation of the three risk indices and the processing of their source data are documented through executable notebooks, allowing each published result to be traced from the original input layers through the intermediate variables to the final mapped classes. Three dedicated notebooks correspond to each index:

- 01_Environmental_Heat_Risk_Index_Workflow.ipynb
- 02_Population_Vulnerability_Index_Workflow.ipynb
- 03_Socioenvironmental_Heat_Risk_Index_Workflow.ipynb

Each notebook loads its inputs from the corresponding input datasets, organised by workflow, and records the intermediate calculation steps before exporting the results as figures. The environmental workflow writes a GeoPackage with one layer per family of reporting units and a calculation table for each; the socio-environmental workflow writes a single layer covering all thirteen units, and the population-vulnerability workflow writes the corresponding outputs for census sections. Figures 2-4, 2-5 and 2-6 are generated from the same workflows used to calculate the indices, ensuring consistency between the reported values, spatial datasets, and graphical outputs.

The analytical workflows were implemented in Python 3.14 using NumPy 2.5, pandas 3.0, GeoPandas 1.1, Shapely 2.1, Rasterio 1.5 and Matplotlib 3.11, with spatial processing in ETRS89 / UTM zone 30N (EPSG:25830). Complementary tools were used to generate and preprocess local inputs: QGIS for satellite and geospatial processing, UMEP Solar Radiation: Shadow Generator for solar exposure and shade, artificial-intelligence detection and very-high-resolution WorldView-3 imagery for vegetation mapping, and field measurements for pavement characterisation. The final environmental, vulnerability and socio-environmental indices were calculated through the dedicated Python workflows described above. These tools do not constitute an independent climate-risk framework but provide the locally derived inputs needed to refine the spatial application of the CLIMAAX assessment. Data sources, spatial scales, weighting criteria, processing steps, uncertainties, and methodological limitations are documented throughout the assessment and supporting documentation to ensure transparent and reproducible final prioritisation.

The following three tables summarise the datasets and derived variables used for this local fine-tuning. They show how the Phase 1 climate-risk framework was complemented with local information on exposure, mitigation capacity, vulnerability, and impact, while the subsequent sections describe the processing and interpretation of each dataset in greater detail.

Table 2-3. Data overview for local fine-tuning of extreme heat and solar-exposure assessment.

Hazard data	Vulnerability data	Exposure data	Impact metrics / Risk output
Weekly Landsat 8 LST rasters, June–September 2025	Not applicable	Municipality, principal settlements, main urban centre, and census sections	Summer-average LST and mean LST by settlement and census section
Aggregated summer LST	Not applicable	Land-cover categories and functional land uses	LST distribution by land-cover and land-use category
Aggregated summer LST	Not applicable	Municipality, principal settlements, and urban spatial units	LST clusters, hotspots and coldspots using Local Indicators of Spatial Association and Getis-Ord Gi*
Solar position and obstruction model based on the PNOA Digital Surface Model	Limited shade continuity and heat-regulation capacity	Streets, squares, pedestrian routes, open spaces, mobility areas, and other locations	Direct solar-exposure map, total-shade map, estimated daylight hours and percentage of the study area by shade class

Table 2-4. Data overview for local fine-tuning of environmental heat-regulation capacity

Hazard data	Vulnerability data	Exposure data	Impact metrics / Risk output
Incoming solar radiation and summer heat	Pavement type and properties: reflectance, absorptance, and thermal emittance, from pavement mapping and two field campaigns	Streets, pavements, squares, car parks, and other exposed urban surfaces	Pavement inventory by type and area; reflectance, absorptance, and emittance for 34 samples; identification of materials with greater heat-absorption and storage potential
Not applicable	Limited canopy extent, small crowns, low vegetation density, and discontinuous distribution	Trees, palms and shrubs in the main urban centre and principal settlements, and the spaces they influence	Georeferenced inventory from Maxar WorldView-3, AI detection, and manual validation; species/type, crown diameter, height, density, and canopy coverage
Not applicable	Limited green coverage, low vigour and reduced foliar development	Tree and shrub polygons plus grass, gardens, hedges, and low shrubs	Integrated green-cover map from AI inventory and NDVI-SAVI matrix; total and additional green cover; vigour and LAI-proxy classes 1–5
Not applicable	Low species richness and diversity, species dominance, and uneven distribution	Inventoried trees, palms and shrubs in the main urban centre and settlements	Species abundance and composition, richness, Shannon index, density and coverage by district and settlement
Future temperature, heat-stress duration, and water-deficit increases under intermediate and extreme scenarios	Tree thermal sensitivity based on Photosystem II efficiency, cumulative physiological fatigue, and shrub drought tolerance	Existing trees and shrubs exposed to future heat and aridity	Climate-resilience classification by species and element; severe- and critical-risk maps; identification of vegetation likely to lose functionality
Not applicable	Limited structural development from small trees and discontinuous canopy	Individually inventoried trees and palms in the main urban centre and settlements	Crown diameter, height, DBH, total leaf area, above-ground biomass, and individual canopy coverage estimated through allometric equations
Extreme heat, high solar radiation, and dry atmospheric conditions	Limited thermal-regulation capacity due to reduced crown size, leaf area, biomass, canopy continuity, or species suitability	Streets, squares, pedestrian routes, residential areas, green spaces, and other vegetation-influenced locations	CESYT Green Metabolism Matrix: potential shade, air-temperature and humidity regulation, solar-radiation, UVA and UVB reduction, and annual CO_2 absorption
Summer-average LST, June–September 2025	Small green-space size, limited canopy, discontinuous vegetation, low foliar development, and impermeable surfaces	Green spaces and immediate surroundings	Mean LST inside and outside green spaces, local cooling effect, and thermal performance by size, structure, and vegetation continuity
Summer-average LST, June–September 2025	Low canopy coverage and limited Urban Green Infrastructure continuity	Regular grids, districts, settlements, and main urban centre	Spatial relationship between canopy coverage and LST; identification of areas where greater canopy coincides with more moderate temperatures

Table 2-5. Data overview for environmental and socio-environmental heat-risk assessment

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
Normalised aggregated summer LST	Tree-canopy and total-shade deficit	Census sections and principal settlements	Environmental Heat Risk Index and map
Not applicable	Age vulnerability, income vulnerability, and educational vulnerability from INE, 2024	Resident population by census section	Population Vulnerability Index
Environmental Heat Risk Index	Population Vulnerability Index	Resident population and census sections	Socio-environmental Heat Risk Index and map

Overall, this approach establishes a traceable link between the Phase 1 CLIMAAX climate-risk framework, the locally generated Phase 2 datasets and the final environmental, social, and socio-environmental risk outputs used for adaptation planning.

2.3.1.2. Supporting analysis

2.3.1.2.1. Land Surface Temperature

Land Surface Temperature was used to characterise persistent spatial differences in surface heating during summer 2025, using all available Landsat 8 Surface Temperature rasters from June to September, which provided weekly coverage of Huércal-Overa.

The Landsat-8 Thermal Infrared Sensor acquires its thermal bands at a native ground resolution of approximately 100 m. Standard Landsat products resample the thermal information to a 30 m grid, and the Landsat Collection 2 Level 2 Surface Temperature product is distributed at 30 m spatial resolution. For this project, the input rasters were subsequently resampled to a 20 × 20 m grid. This resampling provided a common working grid for the local analyses but did not create additional spatial information beyond the original thermal observations.

A pixel-wise arithmetic mean was calculated from all valid summer observations. For each output pixel, the calculation combined the available values at the same location across the complete June to September period.

No additional thermal modelling was applied by the project after preparation of the source rasters. The resulting summer-average raster was treated as the representative surface-temperature layer for the environmental assessment.

Mean summer LST was then extracted for the 100 × 100 m grid cells and census districts used in the assessment. These zonal summaries supported territorial comparison and provided the LST component used later in the Environmental Heat Risk Index, while the continuous raster was retained for identifying local thermal patterns within each area.

Land Surface Temperature represents the radiometric temperature of the ground and other surfaces observed by the satellite. Its role in the assessment is to identify persistent spatial patterns of surface heating, which are interpreted together with shade, vegetation, and urban characteristics.

2.3.1.2.2. Solar exposure and shade

Solar exposure and total physical shade were modelled using the Urban Multi-scale Environmental Predictor (UMEP) tools available through QGIS. The shadow calculation used the national PNOA Digital Surface Model as the principal representation of terrain, which includes elevation information for buildings and other perturbing elements within the study area.

The shadow model was configured to simulate the position of the sun and the resulting cast shadows during daylight hours. Simulations were produced at 30-minute intervals throughout the period from June to September. To reduce computational requirements, the calculation was not repeated for every individual day. Instead, one representative day (the first selected day of each weekly period) was simulated, producing a sequence of weekly summer simulations.

For every representative day, the model generated the expected shadow conditions at each 30-minute time step. The model accounted for shadows produced by the built environment and incorporated vegetation height so that tree-generated shadows could also be represented.

UMEP's daily shadow tools can generate individual shadow rasters for each step and an aggregated raster representing the fraction of the simulated period during which a pixel receives sunlight. When the aggregated output represents sunshine, the corresponding shade fraction must be calculated by inversion.

The project outputs were aggregated to create a summer indicator of total physical shade. This layer represents the relative temporal availability of shade under the simulated solar conditions. It includes shade generated by buildings and vegetation and therefore describes physical obstruction of direct sunlight.

The resulting shade layer was summarised for the 100 × 100 m grid cells and census districts used in the assessment. These summaries were used to identify areas with prolonged solar exposure and to derive the shade component of the Environmental Heat Risk Index.

2.3.1.2.3. Pavement analysis

Pavements were analysed as a local factor influencing the thermal behaviour of urban space. The assessment combined pavement cartography with two field campaigns conducted on 28 May and 17 June 2026. A total of 34 representative pavement samples were characterised, covering the main surface types present in the urban core, including asphalt, asphalt-cement mixtures, cobblestones of different colours and finishes, tiles, marble, ornamental stone, and artificial turf. For each sample, the material type, location, and geographic position were recorded.

Solar reflectance was measured directly using a Surface Optics 410-Solar portable reflectometer, while thermal emittance was measured with a Surface Optics ET-100 portable emissometer. Solar absorptance was calculated as the complementary value of reflectance, assuming negligible transmittance for opaque pavement materials.

Reflectance, absorptance, and thermal emittance were interpreted jointly rather than as direct measures of surface temperature. The resulting dataset provided a local radiative characterisation of the main urban pavement types and supported the identification of surfaces with greater potential to absorb and retain heat, informing the subsequent adaptation analysis.

2.3.1.2.4. Vegetation, green cover, and ecosystem services

A high-resolution vegetation inventory was produced in Phase 2, using 30 cm spatial-resolution visible and near-infrared satellite imagery acquired specifically for the project. The imagery provided sufficient spatial detail to identify individual vegetation elements and their approximate crown extent across the main urban centre and the other areas included in the analysis. Vegetation detection was supported by a medium-sized deep-learning object-detection architecture of 20.1 million parameters. The model was trained using annotated satellite-image examples representative of the vegetation and urban conditions present in the study area.

The trained model was applied systematically to the acquired imagery to generate an initial inventory of detected vegetation objects. Automated detection was followed by a detailed manual quality-control process. The model outputs were visually reviewed to identify false-positive detections, omitted vegetation elements, inaccurate object locations, and incorrect crown geometries. Manual corrections were applied where necessary to ensure the integrity and practical usability of the final dataset.

The validated inventory was used to create the tree-canopy polygon layer employed by the Environmental Heat Risk workflow. The polygons provided the spatial basis for calculating canopy area, canopy coverage, and canopy deficit within the 100×100 m grid and the relevant territorial units.

The vegetation inventory was complemented with spectral information derived from Maxar WorldView-3 imagery. NDVI and SAVI were combined to identify additional vegetated surfaces not represented by the individual object-detection process, including herbaceous vegetation, hedges, gardens, and other low-growing green cover. Areas already represented by inventoried trees and shrubs were excluded to avoid double counting, producing an integrated green-cover layer combining the AI inventory with complementary vegetation. The combined NDVI-SAVI response was also classified into five relative classes and used as a proxy for vegetation vigour and foliar development. Each index was first reclassified into five levels on its own scale, NDVI at 0.25, 0.40, 0.60 and 0.75 and SAVI at 0.30, 0.45, 0.65 and 0.80, and the two were then combined into a single two-digit value as NDVI * 10 + SAVI, so that the first digit carries the NDVI level and the second the SAVI level. Combinations low on either index, namely 11 to 14, 21, 22, 31 and 41, were discarded as not representing meaningful green cover. The remaining values were grouped into the five final vigour classes at breaks of 15, 20, 30 and 40, running from very low to very high foliar development.

This inventory was subsequently used to characterise vegetation structure and composition through indicators including species abundance, richness, Shannon diversity, tree density, and canopy coverage. Crown geometry and species information were also combined with allometric relationships to estimate structural parameters, including crown diameter, height, DBH, total leaf area, and above-ground biomass. These variables supported the assessment of potential ecosystem services through the CESYT Green Metabolism Matrix, a proprietary scientific tool developed in collaboration with the University of Seville. The tool enables the estimation of biometric parameters and ecosystem-service values for the main species used in urban landscaping, including shade provision, temperature and humidity regulation, solar-radiation reduction, and annual CO_2 absorption. These are the ecosystem services most directly related to thermal comfort and climate adaptation.

These vegetation datasets were used at different stages of the Phase 2 assessment. Tree-canopy coverage provided the vegetation component of the Environmental Heat Risk Index, while species and structural information supported the climate-resilience and ecosystem-service analyses. Canopy coverage and integrated green cover were also compared with summer Land Surface Temperature to assess the relationship between Urban Green Infrastructure and local thermal conditions. Results were summarized at different spatial scales, including individual vegetation elements, 100 × 100 m grid cells, urban districts, and principal settlements.

These additional analyses provide context for interpreting environmental heat regulation, but do not all enter directly into the Environmental Heat Risk Index.

2.3.1.3. Workflow 1 - Environmental Heat Risk Index

The Environmental Heat Risk Index was designed to integrate three complementary dimensions of local outdoor heat exposure and mitigation capacity: tree-canopy deficit, total-shade deficit, and summer Land Surface Temperature. These variables were selected because together they represent distinct but interacting components of urban heat risk: vegetation-based thermal regulation, direct protection from solar radiation and the observed thermal response of the surface. Other potentially relevant variables (e.g. land-cover characteristics, absorptance and emissivity, pavement

reflectance) were analysed but not incorporated into the index because their influence is partly reflected in LST and/or in the shade and canopy variables. Including them as additional components could therefore introduce redundancy and double counting within the composite indicator.

Tree-canopy deficit received the highest weight (40%) because urban tree canopy provides multiple and simultaneous heat-mitigation mechanisms, particularly solar shading and evapotranspirative cooling. Systematic reviews and empirical studies identify urban vegetation, and particularly trees, as an effective mechanism for reducing urban temperatures and improving outdoor thermal conditions (Bowler et al., 2010; Rahman et al., 2019; Nasrollahi et al., 2020). Total-shade deficit received a weight of 35% because direct solar exposure is a major determinant of outdoor thermal stress. Shading reduces incoming short-wave radiation and mean radiant temperature, one of the main climatic variables influencing outdoor thermal comfort, and both vegetation- and structure-based shading are recognised as important urban heat-mitigation strategies (Nasrollahi et al., 2020; Nicholson et al., 2024). Normalised summer LST received a weight of 25% because it provides an observed spatial indicator of persistent surface heating and allows comparatively hotter and cooler areas to be identified. Satellite-derived LST is widely used to characterise surface urban heat patterns, but it represents radiometric surface temperature rather than air temperature or human thermal comfort and is strongly influenced by land-cover characteristics, surface properties, moisture conditions, and acquisition conditions (Zhou et al., 2019). For this reason, LST was assigned a lower weight than the two variables representing direct local heat-mitigation capacity. The final 40–35–25 weighting scheme was therefore defined through expert judgement informed by the scientific literature, the functional role of each component in heat exposure and regulation, and the need to minimise redundancy between correlated environmental variables.

2.3.1.3.1. Workflow inputs

Table 2-6. Input layers of the Environmental Heat Risk Index workflow.

Layer	Format	Content used
Summer-average LST raster	Raster, °C	Mean surface temperature per pixel
Solar exposure rasters	Raster, sunlit fraction 0-1	Mean sunlit fraction per pixel
Tree inventory grid	100 × 100 m grid polygon grid	Canopy area allocated to grid units
Census-unit geometries	Polygon-geometry dataset	Analysis and mapping units

All layers were projected to EPSG:25830 before processing. The three upstream layers (the tree inventory, the LST raster and the solar exposure raster) were produced by the project team. They enter the workflow as inputs and are not recomputed within it.

2.3.1.3.2. Input data preprocessing.

The workflow begins by projecting every input to EPSG:25830 and loading the reporting-unit geometries: the seven districts of the main urban centre and the six principal settlements.

Canopy is transferred from the 100×100 m grid to the reporting units as an absolute quantity. Each grid cell is intersected with the units, and the canopy area and tree count of the cell are allocated to each unit in proportion to the share of the cell falling inside it. The allocated quantities are then summed per unit, and canopy coverage is calculated as allocated canopy area over intersected unit area. A tree crown spanning two cells therefore contributes to both in proportion to its overlap, and no canopy is counted twice or lost at unit boundaries. For solar exposure, the workflow takes the arithmetic mean of the valid modelled pixels falling inside each unit. Pixels the model did not reach are excluded from the mean.

Solar exposure is held as a set of 2 m rasters: one covering the main urban centre and one for each principal settlement, each storing the fraction of the simulated summer daylight period during which the pixel receives direct sun. The zonal mean is taken from the raster covering the unit, using the same procedure as for surface temperature.

The result of preprocessing is a single analytical table holding, for each reporting unit, its canopy coverage, its mean summer surface temperature, and its mean sunlit fraction.

2.3.1.3.3. Environmental Heat Risk Index computation

The three components of the index are placed on a common 0 - 1 scale by min–max normalisation across the units being compared. Districts and settlements are normalised separately, each family against its own minimum and maximum, because the two sets differ systematically in density and urban form and a joint normalisation would compress the variation within each.

Vegetation cover is inverted after normalisation to express a deficit, so that the unit with the greatest relative canopy provision scores 0 and the unit with the least scores 1. Surface temperature and solar exposure enter directly since higher values of both increased risks.

The index is the weighted sum:

EHRI = 0.40 * canopy deficit + 0.35 * solar exposure + 0.25 * normalised summer LST

The continuous index is retained together with each normalised component, so that units reaching similar scores by different routes can be distinguished. The index is then classified into three levels at thresholds of 0.33 and 0.66.

The index is a relative territorial prioritisation indicator. It ranks units against one another within this study area and is not an absolute measure of health damage, air temperature, or thermal comfort.

2.3.1.3.4. Environmental Heat Risk Index assessment

Figure 2-4 shows the spatial distribution of environmental heat risk in the main urban centre. District 4 was the only district classified as high risk (0.90), combining the highest mean summer LST and solar exposure with low canopy provision for its large area. Although it contains many trees, their distribution and canopy continuity are insufficient to offset open streets, peripheral spaces, and residual agricultural land. This shows that thermal regulation depends not only on tree numbers, but also on crown size, spatial distribution, and canopy continuity.

Districts 3 and 7 had low environmental risk (0.19 and 0.21), with District 3 benefiting from the highest relative canopy coverage and cooler vegetated areas, and District 7 from favourable canopy provision, low solar exposure, and moderate surface temperature. Districts 1, 2, 5 and 6 had moderate risk (0.44–0.57), although their drivers differed: District 2 combined the lowest canopy coverage with the lowest solar exposure in this group, while District 6 had diverse vegetation but discontinuous shade. These differences show that similar risk levels can result from different combinations of exposure and mitigation capacity.

Among the six principal settlements, Las Labores was the only one with high environmental risk (0.69), due to its mean summer LST of 35.04 °C, the highest of all reporting units. El Saltador, La Hoya, San Francisco, Santa María de Nieva and Úrcal had moderate risk (0.36–0.65), and none had low risk. However, similar scores may reflect different combinations of canopy coverage, solar exposure, and surface temperature.

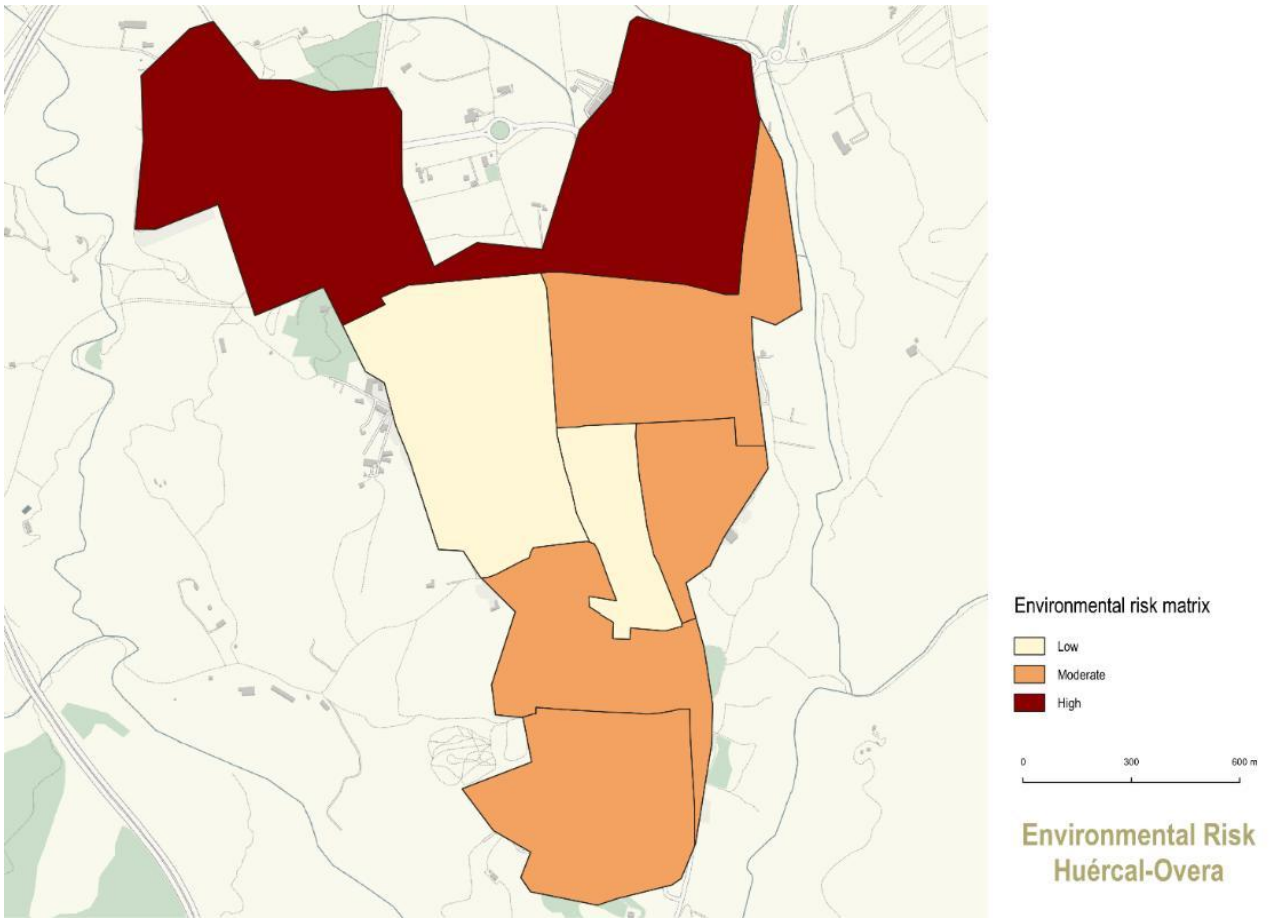


Figure 2-4. Environmental Heat Risk Index in the main urban centre of Huércal-Overa. Source: LST, solar exposure and tree canopy. Self-produced using data layers detailed in chapter 2.3.1.3.1 - 01_Environmental_Heat_Risk_Index_Workflow.ipynb

Overall, the Environmental Heat Risk Index shows that risk results from the convergence of multiple unfavourable conditions rather than surface temperature alone. District 4 is the clearest example, where high summer LST, high solar exposure and insufficient canopy reinforce one another, while in other districts favourable conditions partly offset existing deficits. Adaptation should therefore target the dominant local driver by increasing canopy and effective shade, improving vegetation continuity, and addressing heat-accumulating surfaces and public spaces.

2.3.1.4. Workflow 2 - Population Vulnerability Index

The Population Vulnerability Index is a substantial improvement over Phase 1, which used age as its sole vulnerability proxy. The Population Vulnerability Index was constructed to represent both physiological sensitivity to extreme heat and differences in adaptive capacity across Huércal-Overa. Three indicators consistently available at census-section level were selected: age vulnerability, represented by the proportion of residents aged 0–4 and 65 years or older; economic vulnerability, represented by mean net income per person; and educational vulnerability, represented by the proportion of residents aged 15 or over with primary education or below.

These dimensions are widely recognised in heat-vulnerability research, where age, socioeconomic conditions and education are recurrently used to characterise sensitivity and adaptive capacity (Reid et al., 2009; Bao et al., 2015). The final index assigned a higher weight to age vulnerability (45%) because age represents a direct physiological determinant of heat sensitivity, with older people, infants and young children consistently identified among the groups at greatest risk from extreme

heat (World Health Organization, 2026). Economic vulnerability received a weight of 35%, reflecting the strong influence of household resources on adaptive capacity, including access to cooling, adequate housing and other protective measures; empirical evidence also shows that lower-income households tend to have reduced capacity to implement technical heat adaptation measures (Osberghaus & Abeling, 2022). Educational vulnerability received a complementary weight of 20%, as education is commonly associated with broader socioeconomic vulnerability and access to information and preventive resources, but its relationship with heat-health impacts is less direct and partially overlaps with economic conditions (Reid et al., 2009). The 45–35–20 weighting scheme was therefore defined through expert judgement informed by the literature and the conceptual distinction between physiological sensitivity and adaptive capacity, rather than being adopted directly from a single published Heat Vulnerability Index.

2.3.1.4.1. Workflow inputs

Table 2-7. Input layers of the Population Vulnerability workflow.

Variable	Source table	Reference Year	Unit
Total resident population	Age table (69109)	2025	people
Population aged 0–4	Age table (69109)	2025	people
Population aged 65 and over	Age table (69109)	2025	people
Mean net income per person	Income table (30842)	2023	€ per person
Population aged 15 and over	Education table (66637)	2024	people
Population aged 15 and over with primary education or below	Education table (66637)	2024	people
Census section identifier (CUSEC)	All three tables	2023-2025	ID Code

All three tables are published by the Spanish National Statistics Institute and linked by census section code. The workflow reads the source counts directly and derives the required ratios internally, avoiding dependence on intermediate files.

2.3.1.4.2. Input data preprocessing.

The three source tables are read at census-section level and joined on the census section code, which is common to all of them and requires no spatial operation.

Two ratios are derived from the raw counts: the combined proportion of residents aged 0 - 4 and 65 or over, and the proportion of residents aged 15 or over whose highest attainment is primary education or below. Mean net income per person requires no ratio and is used as published.

Ten census sections cover the municipality. Seven of them make up the main urban centre and correspond to the seven districts used throughout the assessment; the remaining three cover the principal settlements and the rural area.

2.3.1.4.3. Population Vulnerability Index computation

All three indicators are normalised to 0 - 1 by min–max across the analysed sections. Age and education are normalised directly since higher values indicate greater vulnerability. Income is normalised and then inverted, so that the lowest-income section receives a value of 1.

The index is the weighted sum:

PVI = 0.45 * normalised age vulnerability + 0.35 * inverted income vulnerability + 0.20 * normalised educational vulnerability

The raw indicators and normalised indicators are all retained, so that sections reaching similar totals through different combinations of disadvantages can be distinguished.

For cartographic presentation, the index is classified into five categories at fixed thresholds of 0.2, 0.4, 0.6 and 0.8 on the 0 - 1 scale. Workflow 3 will later read the continuous index rather than the classified data output.

2.3.1.4.4. Population Vulnerability Index assessment

The results show marked territorial inequalities in social vulnerability across Huércal-Overa: of the ten census sections analysed, one had very high vulnerability, two high, three medium, three low and one very low. Section 0405304002 recorded the highest PVI (0.93), driven by high age, income, and educational vulnerability. Sections 0405305002 and 0405304001 followed (0.66 and 0.65), due to age structure, with section 0405305002 also showing comparatively high educational vulnerability.

Within the main urban centre, PVI values ranged from 0.58 in District 1 to 0.00 in District 6 (Figure 2-5). District 6 showed the most favourable values across all three indicators: the lowest share of residents aged 0–4 and 65 or over, the lowest share with primary education or below, and the highest mean net income. This confirms that population vulnerability is unevenly distributed and that districts with similar environmental exposure may differ in social sensitivity and adaptive capacity.

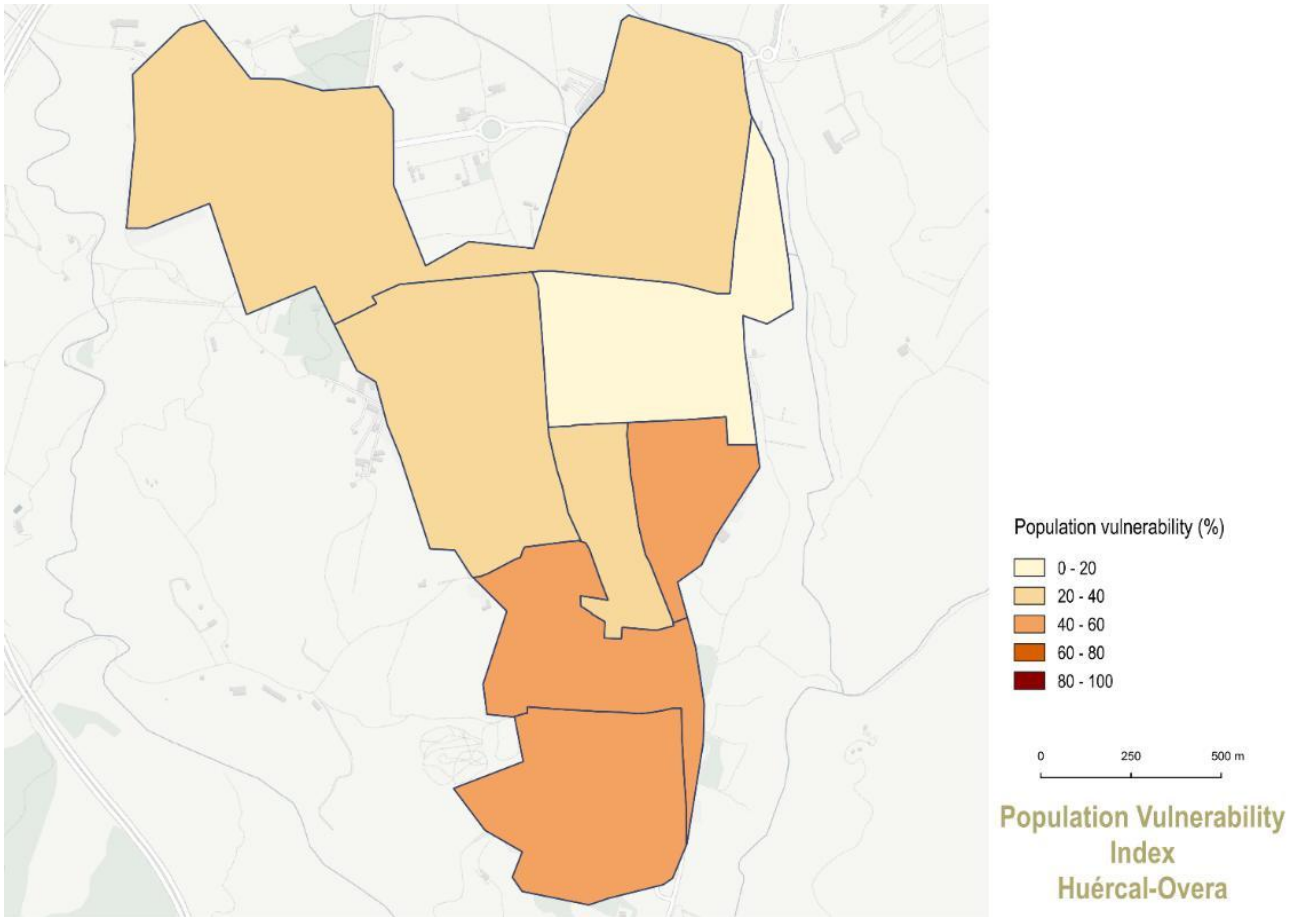


Figure 2-5. Population Vulnerability Index by census section in Huércal-Overa. Source: INE age, income, and education data. Source: Self-produced using data layers detailed in chapter 2.3.1.4.1. - 02_Population_Vulnerability_Index_Workflow.ipynb

The PVI is a relative territorial measure: a low value indicates a more favourable position compared with other census sections, not the absence of vulnerable residents. It excludes variables for which homogeneous census-section data were unavailable, including health status, housing quality, indoor

thermal conditions, access to air conditioning, energy poverty, social isolation, support networks, and proximity to healthcare services. These factors were considered qualitatively through stakeholder engagement but not included in the quantitative calculation.

Similar PVI scores may also result from different combinations of physiological sensitivity and adaptive-capacity constraints. In some sections vulnerability is driven by older people or young children, while in others lower income or educational attainment contributes more strongly. Therefore, similar overall vulnerability levels may represent different vulnerability profiles and require different adaptation responses.

This distinction has direct implications for adaptation planning. Areas where age-related sensitivity is the main driver may require stronger protection of older people and young children, improved access to shaded and thermally safer spaces, and targeted heat-health communication. Where socioeconomic vulnerability is more important, adaptation may require better access to cooling, affordable protective measures, and social-support mechanisms. The PVI should therefore be used not only to rank census sections, but also to identify the underlying vulnerability profile and guide the most appropriate type of intervention.

2.3.1.5. Workflow 3 - Socio-environmental Heat Risk Calculation

The Socio-environmental Heat Risk Index was developed to integrate environmental heat exposure and regulation capacity with the social vulnerability of the resident population. It combines the Environmental Heat Risk Index from Workflow 1 with the Population Vulnerability Index from Workflow 2, allowing areas with similar environmental conditions to be differentiated according to population sensitivity and adaptive capacity. Environmental risk represents the combined influence of summer Land Surface Temperature, solar exposure, and tree-canopy deficit, while population vulnerability represents demographic and socioeconomic conditions through age, income, and education. The two dimensions were kept separate until the final integration, which provides a territorial prioritisation indicator identifying where unfavourable environmental conditions coincide with greater population vulnerability.

Both dimensions were given equal importance in the final calculation. The two indices are already expressed on a common 0 - 1 scale, so they are combined by direct addition, with neither dimension weighted above the other. Combining the continuous scores rather than their classes preserves the differences between districts that would otherwise fall within the same class.

2.3.1.5.1. Workflow inputs

Table 2-8. Input layers of the Socio Environmental Risk Index workflow.

Layer	Format	Content used
Environmental Heat Risk Index	GeoPackage	Environmental index score and for each district and principal settlement
Population Vulnerability Index	GeoPackage	Population Vulnerability Index score and vulnerability class by census section

Both input layers are outputs of the preceding workflows and enter Workflow 3 as completed indices. Workflow 3 uses their final continuous scores from the previous 2 notebooks as the basis for the socio-environmental integration.

2.3.1.5.2. Input data preprocessing.

The Environmental Heat Risk Index is calculated for the seven districts of the main urban centre and the six principal settlements, whereas the Population Vulnerability Index is calculated at census-section level.

For the main urban centre, the seven reporting units were obtained by intersecting the census-section geometries with the defined Huércal-Overa urban study-area boundary. This operation clips the census sections to the territorial extent used in the environmental assessment without combining them, so each resulting district retains the Population Vulnerability Index value of its corresponding census section.

For the principal settlements, the Population Vulnerability Index is assigned from the census section in which each settlement is located. As some of the larger peripheral census sections contain more than one settlement, different settlements may therefore share the same vulnerability value.

The resulting dataset contains, for each urban district and principal settlement, its Environmental Heat Risk Index and the Population Vulnerability Index associated with its corresponding census section. These values provide the common basis required for the socio-environmental integration.

2.3.1.5.3. Socio-environmental Heat Risk Index computation

The Environmental Heat Risk Index and the Population Vulnerability Index are initially expressed on different scales. The environmental index ranks units by physical and ecological conditions; the vulnerability index ranks them by the sensitivity and adaptive capacity of their residents.

Integrating them identifies where adverse environmental conditions coincide with limited social capacity to cope with them.

Before the two can be combined they must describe the same units. The environmental index is calculated on the seven districts of the main urban centre; the vulnerability index is calculated on the ten census sections of the municipality.

The two indices are then added to give a combined score, and that total is min-max normalised across the seven districts so that the result again spans 0 - 1. The normalised score is classified into low, medium, and high by natural breaks (Jenks), which places the two class boundaries at the widest gaps in the observed distribution.

The seven scores fall into three groups: 0.00-0.14, 0.71-0.77 and 1.00; and the boundaries fall between them, at 0.14 and 0.77.

It is to be kept in mind that Min-max normalisation is relative: the district with the highest combined score always scores 1 and the lowest always 0, so the classification ranks districts against one another within the urban centre. A district can therefore sit in a different class on the environmental and the socio-environmental maps because the combined scale is classified on its own terms rather than inheriting the environmental thresholds.

2.3.1.5.4. Socio-environmental Heat Risk Index assessment

In the main urban centre (Figure 2-6), integrating environmental risk and population vulnerability confirms District 4 as the main priority and reorders the remaining districts. District 4 has the highest combined score and is the only district with high socio-environmental risk, as its environmental deficits are not offset by comparatively lower population vulnerability. Districts 1, 2 and 5 have

medium risk; District 1 rises from fifth to second because moderate environmental conditions coincide with the highest population vulnerability in the urban centre. Districts 3, 6 and 7 have low risk, with District 6 moving from medium environmental to low socio-environmental risk because it records the lowest population vulnerability of the ten census sections.

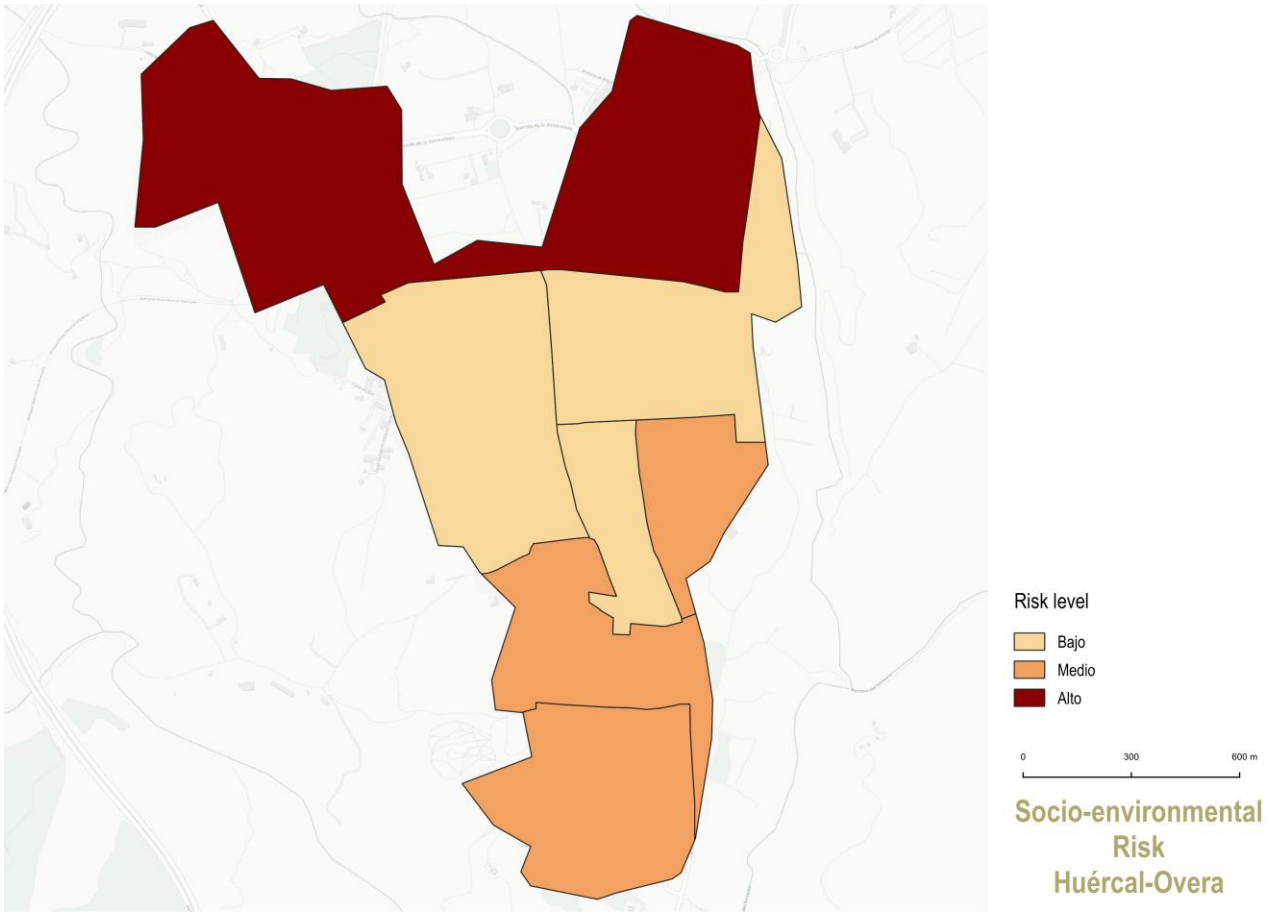


Figure 2-6. Socio-environmental Heat Risk Index in the main urban centre of Huércal-Overa. Source: Environmental Heat Risk Index and Population Vulnerability Index. Source: Self-produced using data layers detailed in chapter 2.3.1.5.1. - 03_Socioenvironmental_Heat_Risk_Index_Workflow.ipynb

All six principal settlements have high socio-environmental risk. El Saltador, La Hoya, San Francisco, Santa María de Nieva and Úrcal move from moderate environmental to high integrated risk because of high population vulnerability, while Las Labores remains high because both dimensions are unfavourable. This pattern is strongly influenced by the census structure, as the settlements fall within the two census sections with the highest vulnerability values. It is also consistent with contextual factors not directly quantified by the indices, including more limited access to local services and cooling facilities and greater dependence on private mobility or outdoor activities.

The three outputs should therefore be interpreted together: the Environmental Heat Risk Index identifies where physical and ecological conditions intensify exposure; the Population Vulnerability Index identifies where residents are more sensitive or have fewer resources to cope; and the Socio-environmental Heat Risk Index identifies where both dimensions coincide.

These different risk profiles require differentiated adaptation strategies. District 4 primarily needs environmental and spatial interventions to reduce exposure and improve shade, canopy continuity and public-space design; District 1 requires greater attention to vulnerable populations and sensitive

uses, together with targeted physical improvements; and Las Labores requires an integrated response addressing both environmental deficits and social vulnerability. The remaining settlements also require attention because moderate environmental conditions do not offset their high social vulnerability.

Indirect impacts were not modelled through specific health, economic or energy-demand models, but potential effects on public-space use, cooling and irrigation demand, outdoor work, healthcare and social services, vegetation functionality, and agricultural and livestock activity were considered. The maps should therefore be interpreted as territorial prioritisation tools rather than direct estimates of health impacts, economic losses, or service disruption.

Overall, adaptation priorities cannot be defined from temperature or environmental exposure alone. Combining thermal conditions, shade, canopy coverage, and population vulnerability provides a more robust basis for identifying where impacts are likely to be greatest and for prioritising districts, settlements, and public spaces in Phase 3.

2.4 Key Risk Assessment Findings

2.4.1 Mode of engagement for participation

Stakeholder engagement for risk evaluation built on the process described in Section 2.1.5, which included a technical session with municipal staff, consultation with local organisations, an online survey, and a participatory heat map.

For the Key Risk Assessment, stakeholders contributed by interpreting and validating the technical results. Municipal staff and local participants confirmed significant spatial differences in heat risk and highlighted that district-level classifications should be interpreted alongside public-space use, sensitive facilities, and the location of vulnerable groups.

Their feedback highlighted factors not fully captured by the spatial datasets, including recent land-use changes, vegetation loss and the importance of healthcare environments, school surroundings, pedestrian routes and intensively used public spaces. It also showed that areas classified as having moderate overall risk may contain specific areas with substantial heat-exposure problems.

This evidence was used to refine the interpretation of severity, urgency, and overall risk priority, although it was not included directly in the calculation of the risk indices. Participation was more representative of the main urban centre than of the smaller settlements, and some priority groups were represented indirectly through associations and municipal services. Further engagement is therefore planned during Phase 3 to discuss and refine the proposed adaptation measures.

2.4.2 Gather output from Risk Analysis step.

The Key Risk Assessment evaluated the current and future significance of extreme heat using the main outputs of the regionalised analysis: summer Land Surface Temperature, solar exposure and total shade, tree-canopy distribution and continuity, the Environmental Heat Risk Index, the Population Vulnerability Index, the Socio-environmental Heat Risk Index, spatial comparisons across the urban centre, census districts and principal settlements, and vegetation condition, climate resilience and thermal-comfort ecosystem services.

The environmental index identified where high surface temperatures, limited shade and insufficient canopy coincide; the vulnerability index differentiated census sections by age, income, and education; and their integration showed where adverse environmental conditions overlap with lower

social adaptive capacity. The assessment also incorporated the projected increase in heatwave frequency, duration and intensity from Phase 1 and the future capacity of Urban Green Infrastructure to regulate heat under greater temperature, drought, and water stress.

The combined evidence shows that extreme-heat risk depends not only on hazard intensity, but also on environmental deficits, adaptive capacity, and vegetation resilience. This integrated interpretation underpins the assessment of severity, urgency, resilience capacity, and overall risk priority.

2.4.3 Assess Severity

Severity was assessed against the four CLIMAAX categories of limited, moderate, substantial, and critical, considering the frequency and intensity of extreme heat, territorial extent, affected populations, and sectors, irreversible or cascading consequences, and stakeholder evidence.

Current extreme-heat risk in Huércal-Overa was classified as substantial. Heatwaves are recurrent and increasing in frequency and duration, while high surface temperatures, prolonged solar exposure, limited shade, and discontinuous tree-canopy coverage affect extensive areas of the main urban centre and the principal settlements. Current impacts include reduced thermal comfort and public-space usability, greater exposure of outdoor workers, and increasing pressure on healthcare, social services, vegetation, and water resources. The territorial results reinforce this classification. District 4 presented high environmental risk. Once social vulnerability was incorporated, District 4 remained the only district classified as having high socio-environmental risk, while Districts 1, 2 and 5 presented medium risk and Districts 3, 6 and 7 were classified as low. District 1 records the highest population vulnerability within the urban centre. These results show that severity depends not only on physical exposure, but also on population sensitivity and adaptive capacity.

Current risk was not classified as critical because no widespread irreversible damage, systematic disruption of essential services, or documented large-scale heat-related mortality and financial losses were identified during the analysed period. Nevertheless, serious health impacts, vegetation decline and cascading effects on water and energy demand, outdoor work, public services, agriculture, livestock farming, and ecosystem services remain possible, supporting a substantial rather than moderate classification.

Future severity was assessed as substantial under the intermediate scenario and critical under the high-emission scenario. By around 2060, the annual number of heatwave days is projected to increase from approximately 10 days historically to more than 15 days under RCP 4.5 and more than 20 days under RCP 8.5. In the most severe projected years, however, annual heatwave exposure may exceed 30 or even 40 days. Average event duration may increase from less than 3 days to nearly 6 days, while annual frequency may rise from approximately two to around four events, with more than six or seven events possible in extreme years. This would increase cumulative exposure, shorten recovery periods, and intensify impacts on older people, children, people with chronic illnesses and outdoor workers, while increasing cooling, irrigation, and emergency-response demand.

The main difference between current and future severity is therefore not only the projected increase in temperature or heatwave frequency, but the accumulation and persistence of exposure. Longer and more frequent events reduce recovery periods for both people and vegetation and may progressively reduce the ability of existing Urban Green Infrastructure to provide shade and cooling. This interaction supports the shift from substantial current severity to potentially critical severity under the high-emission scenario.

Future severity is also influenced by the resilience of Urban Green Infrastructure. Under greater heat, drought and water stress, part of the existing vegetation may lose physiological functionality or require more irrigation and maintenance. This may create a reinforcing cycle in which heat intensifies while environmental regulation capacity declines, potentially leading to ecosystem-service losses and greater pressure on health, water, energy, and economic activities.

Stakeholder feedback refined the severity assessment by confirming that heat already affects daily activities and that impacts vary across the urban centre, smaller settlements, healthcare and school environments, pedestrian routes, and highly exposed public spaces. It also showed that district-level averages may underestimate severity at specific streets or facilities. Decision-makers are increasingly aware of heat risk and its links with urban planning and Green Infrastructure, but technical capacity remains uneven, particularly for interpreting climate projections, vulnerability indicators, and spatial prioritisation tools. Continued technical support and cross-departmental coordination are therefore needed.

Overall, extreme heat already represents a substantial risk in Huércal-Overa and may become critical under the high-emission scenario if exposure, vulnerability, and environmental regulation capacity remain broadly unchanged.

2.4.4 Assess Urgency

Urgency was assessed using the CLIMAAX categories and classified as more action needed at municipal level, with immediate action required in priority locations and for long-lead measures.

The risk is already recurrent and affects daily life, public-space use, vulnerable groups, outdoor workers, vegetation, water resources, and municipal services, so neither no action needed nor watching brief is appropriate. Immediate action is not required everywhere, however, because risk varies spatially. Priority areas include Districts 1 and 4, Las Labores, healthcare settings, school surroundings, pedestrian routes, and intensively used spaces with limited shade.

Urgency increases because future severity may become critical under the high-emission scenario. Extreme heat combines a slow-onset trend with recurrent acute episodes: rising temperatures and aridity worsen progressively, while individual heatwaves can rapidly create health and operational pressures and recur within the same summer, reducing recovery time.

Early action is also required because several structural measures have long implementation and establishment periods. Tree-canopy development, Green Infrastructure reinforcement, public-space redesign, pavement renewal, and irrigation-system improvements may require years before delivering their full benefits. Delaying implementation would therefore increase the period during which exposure rises without a corresponding increase in adaptation capacity. Increasing heat and water stress may also reduce vegetation functionality, reinforcing the need for early diversification and climate-resilient planting.

Stakeholder feedback confirmed that heat impacts are already visible in streets without trees, healthcare environments, school surroundings, highly paved spaces, and pedestrian routes. This supports a phased response combining rapid measures, such as temporary shade, heat-health communication, and support for vulnerable groups, with immediate planning of structural measures that provide medium- and long-term benefits.

Overall, more action is needed across Huércal-Overa, with immediate action in priority locations and for measures requiring long implementation periods.

2.4.5 Understand Resilience Capacity

Resilience capacity was assessed across the CLIMAAX categories of low, medium, substantial, and high, considering financial, human, physical, social, and natural capacity. Huércal-Overa was classified as medium: it has functioning institutions, public services, technical knowledge, and existing adaptation resources, but current financial, human, physical, social, and natural capacities remain insufficient to fully manage the projected increase in extreme-heat risk.

Existing capacity includes municipal responsibilities for urban planning, public-space and green-area management, water, social services, public health, Civil Protection, and emergency response. AEMET heat warnings are disseminated through municipal channels, while healthcare facilities, schools, public services, and local organisations provide a basis for preparedness, communication, and support. LUGIA has further strengthened human and technical capacity through local risk maps, vulnerability indicators, and spatial prioritisation tools.

However, there is not yet a specific local heat-warning system or a fully integrated municipal heat-action plan. Financial capacity is constrained by limited dedicated funding and dependence on sustained municipal investment and external funding. Human and organisational capacity is limited by uneven technical expertise and cross-departmental coordination, while physical capacity remains constrained by insufficient shade, canopy continuity, and protection in priority areas. Social capacity is limited by incomplete information on some vulnerable groups and by uneven participation, particularly in the smaller settlements.

Existing Urban Green Infrastructure provides natural resilience. However, this capacity is unevenly distributed, some public spaces and facilities remain poorly shaded, dark, and highly absorptive pavements increase exposure, and part of the vegetation may lose functionality under increasing heat, drought, and water stress.

Measures already implemented include green-area maintenance, public-space services, emergency and Civil Protection functions, healthcare and social-service provision, warning dissemination and the integration of adaptation and sustainability objectives into local planning. Planned measures include additional shade, reinforcement of Green Infrastructure, Sustainable Urban Drainage Systems, Nature-based Solutions, and the Phase 3 Urban Naturalisation Strategy, which will identify priority opportunity areas and select vegetation adapted to future climate and water conditions.

Overall, the medium resilience classification reflects a functional but incomplete response capacity. Huércal-Overa has a solid institutional and technical basis for adaptation, but resilience must be strengthened through investment, technical support, improved coordination, more targeted engagement with vulnerable groups and smaller settlements, and reinforcement of the municipality's physical and natural protection systems.

2.4.6 Decide on Risk Priority

Extreme heat was assigned a high-risk priority for Huércal-Overa. This priority was determined by jointly considering the severity, urgency and resilience-capacity scores presented in the preceding sections. The evaluation dashboard was completed using the following results:

Table 2-9. Evaluation dashboard for extreme-heat risk in Huércal-Overa.

Evaluation component	Assigned category	Main justification

Current severity	Substantial	Extreme heat is recurrent and already affects thermal comfort, public-space use, vulnerable groups, vegetation, and municipal services.
Future severity	Substantial under the intermediate scenario and critical under the high-emission scenario	Heatwaves are expected to become more frequent, prolonged, and intense, increasing pressure on vulnerable groups and Urban Green Infrastructure.
Urgency	More action needed, with immediate action in priority areas and for long-lead measures	Impacts are already occurring, and structural measures such as canopy development and public-space redesign require early implementation to become effective.
Resilience capacity	Medium	Existing institutions, services, warnings, technical knowledge, and Green Infrastructure provide a basis, but financial, physical, natural and coordination gaps remain.
Overall risk priority	High	Substantial current risk, potentially critical future conditions, increasing urgency, and medium resilience capacity make adaptation a municipal priority.

The dashboard resulted in a high overall priority. Medium resilience capacity reduces part of the risk but does not compensate for substantial current impacts, potentially critical future conditions and the long implementation periods required for structural adaptation.

Within this municipal classification, spatial priorities were differentiated by their main risk drivers. District 1 was prioritised because of social vulnerability, District 4 because of high environmental risk and limited shade and canopy, and Las Labores because both environmental and socio-environmental risk are high. The remaining settlements also require attention because all were classified as having high socio-environmental risk. Healthcare environments, school surroundings, pedestrian routes, poorly shaded streets and public spaces, and areas with concentrated vulnerable populations were also identified as priority locations.

The high overall priority results from the convergence of four factors: substantial current impacts, potentially critical future conditions, the long lead time required for structural adaptation and medium resilience capacity that remains insufficient to offset the projected increase in risk. None of these factors alone determines the priority; it is their combination that makes early and spatially differentiated action necessary. The assessment therefore supports a dual approach: immediate protection of the most exposed people and places, together with medium- and long-term structural measures that increase the municipality's capacity to withstand more severe heat conditions.

2.5 Monitoring and Evaluation

Phase 2 confirmed that heat risk in Huércal-Overa cannot be understood from temperature alone. Shade, tree-canopy coverage, pavement characteristics, vegetation condition and resilience, social vulnerability and public-space use all influence final risk, while district averages may conceal exposed streets, sensitive facilities, and smaller settlements. The main difficulties were integrating datasets with different spatial and temporal resolutions, distinguishing total physical shade from effective pedestrian shade, and the lack of detailed local data on health impacts, housing, indoor temperatures, energy poverty, outdoor workers, and public-space use.

Stakeholders helped validate and interpret the Climate Risk Assessment by identifying exposed spaces, sensitive facilities, land-use changes, vegetation loss, and everyday heat impacts not fully captured by spatial data. Feedback was positive, particularly regarding the identification of priority areas and the integration of environmental and social vulnerability, although participants requested

clearer indicators and greater detail for specific streets, facilities, and smaller settlements. Stakeholders should remain involved during implementation and monitoring.

Learning is ensured through the phased LUGIA process and the reproducible Phase 2 baseline. Periodic updates, documented assumptions, cross-departmental exchange, and evaluation of implemented measures will support continuous learning and integration into municipal planning.

Phase 2 generated new information on summer LST, solar exposure and shade, pavement properties, vegetation structure, green cover, diversity, vigour, climate resilience, ecosystem services, social vulnerability, integrated heat risk, and stakeholder-identified hotspots. Further monitoring would benefit from additional health, housing, indoor-temperature, energy-poverty, public-space-use, outdoor-worker, irrigation-water, and long-term vegetation data, together with periodic field validation.

Final outcomes will be communicated through the Climate Risk Assessment, executive summaries, thematic maps, indicator tables and accessible materials for municipal departments, elected representatives, local organisations, and residents. Municipal websites, social media, meetings, and Phase 3 materials will continue to be used, clearly distinguishing environmental exposure, population vulnerability, and socio-environmental risk.

Huércal-Overa does not yet have a fully integrated municipal heat-risk monitoring system. The planned digital platform will integrate project indicators with AEMET warnings, vegetation management, public-space interventions, and demographic information, allowing the Municipality to monitor priority areas, Urban Green Infrastructure, exposure, vulnerability, resilience, and adaptation implementation. Heat conditions should be monitored seasonally or during extreme events, vegetation annually or seasonally, and canopy, land use, and socioeconomic indicators at longer intervals or after significant change.

The combination of remote sensing, artificial intelligence, field measurements, spatial analysis, vegetation-resilience information, and stakeholder knowledge worked well and improved territorial coverage and reproducibility. The main limitations were uneven data availability, limited participation in some settlements and vulnerable groups, restricted temporal validation, and the need for cautious interpretation of total shade, remotely sensed vegetation condition, and district-level averages.

Resources were used efficiently by combining existing climate, satellite, statistical and municipal data with automated processing and targeted fieldwork. This improved coverage and cost efficiency, although repeated field campaigns and direct participation in some smaller settlements were limited. The results are robust for strategic prioritisation, but site-level verification will still be required before implementation.

Overall, the Climate Risk Assessment improved understanding of heat risk, strengthened public awareness and municipal technical capacity, supported coordination between relevant departments, and provided a stronger basis for planning, investment, and future funding applications. Its long-term impact will depend on implementation, integration into municipal planning and continued monitoring.

2.6 Work plan Phase 3

Phase 3 will translate the Phase 2 risk priorities into two operational outputs: an Urban Naturalisation Strategy for Reducing Heat Risk and a digital platform for integrated Urban Green Infrastructure and climate-risk management. The work will focus on District 4 and Las Labores because of their high

environmental risk, District 1 because of its high population vulnerability, the smaller settlements because of their high combined vulnerability, and sensitive locations such as healthcare and educational facilities, pedestrian routes, public squares, and poorly shaded streets.

The first activity will define strategic objectives and locally adapted naturalisation guidelines to reduce heat exposure, improve thermal comfort, and strengthen resilience. These guidelines will address Urban Green Infrastructure, shade, permeable surfaces and water-sensitive design, considering Huércal-Overa's semi-arid climate, limited water availability, urban morphology, and maintenance capacity.

Phase 2 priorities will then be translated into specific opportunity areas, including streets, squares, routes, facilities, and open spaces. A multicriteria assessment will combine environmental and socio-environmental risk with available space, land ownership, current use, beneficiary population, infrastructure constraints, and technical feasibility, distinguishing between rapid actions, pilot projects, and longer-term transformations.

Potential adaptation measures will be selected according to the dominant risk drivers identified in each location rather than from risk scores alone. Options may include tree and shrub planting, additional shade, soil-permeability improvements, Sustainable Urban Drainage Systems, water-sensitive design, pavement adaptation, shaded pedestrian routes and artificial shade where vegetation is not feasible. Alternatives will be compared according to thermal benefits, spatial compatibility, water and maintenance requirements, costs, compatibility with planned municipal projects, municipal management capacity, and implementation feasibility. Vegetation will be selected according to future climate suitability, drought and heat tolerance, water demand, shade provision, available space, and long-term management needs. The Strategy will establish a phased implementation pathway and potential pilot actions. Municipal departments and local stakeholders will validate the selected spaces and measures, with greater effort to involve the smaller settlements. In parallel, the digital platform will integrate the vegetation inventory, risk indicators, priority areas, proposed measures, and monitoring variables, allowing the Municipality to update information, compare alternatives, track implementation, and evaluate improvements over time.

Phase 3 will not reassess other hazards, such as flooding or territorial-scale drought, nor include detailed design or implementation of measures, as these fall outside LUGIA's scope and would require additional datasets, technical projects, permits, and investment.

3 Conclusions Phase 2- Climate risk assessment

3.1. Strategic conclusions

Conclusion 1. Extreme-heat risk is spatially unequal and cannot be assessed from temperature alone. Phase 2 confirms that extreme heat and recurrent heatwaves already represent a substantial and spatially unequal risk in Huércal-Overa. The local assessment shows that areas with similar Land Surface Temperature may present different levels of risk depending on solar exposure, shade, tree-canopy provision, urban form, and population vulnerability. Adaptation priorities should therefore be based on the combined interpretation of environmental and social conditions rather than on temperature alone.

Conclusion 2. Environmental and social conditions generate different territorial priorities. District 4 presents both the highest environmental risk and the highest socio-environmental risk within the main urban centre. Integrating population vulnerability does not change which district ranks first, but it reorders those below it: District 1 rises from fifth to second because moderate environmental conditions coincide with the highest population vulnerability in the urban centre, while District 6 falls from medium to low because its population vulnerability is the lowest of the ten census sections. Las Labores represents the clearest case of cumulative risk, since both environmental and social conditions are unfavourable. All six principal settlements were classified as having high socio-environmental risk. These results confirm that environmental and socio-environmental outputs should be interpreted together when defining adaptation priorities.

3.2. Operational conclusions for adaptation

Conclusion 3. The presence of vegetation does not necessarily guarantee effective cooling. The assessment confirms that the thermal-regulation capacity of Urban Green Infrastructure depends not only on the presence or number of vegetation elements, but also on crown size, canopy continuity, spatial distribution, vegetation condition, species suitability, and future climate resilience. Larger and more continuous tree canopy provides greater potential for shade and thermal regulation, while fragmented or low-growing vegetation offers more limited direct protection from solar exposure. Adaptation should therefore focus on the functionality and long-term performance of Urban Green Infrastructure rather than on vegetation presence alone.

Conclusion 4. Effective adaptation requires combined action on shade, urban surfaces, and water. The analysis of solar exposure, shade and pavement characteristics shows that unfavourable thermal conditions cannot be addressed through vegetation alone. Dark and highly absorptive surfaces, prolonged solar exposure, and limited effective shade contribute to heat accumulation in streets, squares, mobility areas, and other public spaces. Adaptation should therefore combine tree-canopy reinforcement with effective shading, improved surface materials, greater permeability, Sustainable Urban Drainage Systems, and water-sensitive public-space design. The appropriate combination of measures should respond to the dominant environmental driver in each location.

Conclusion 5. Local knowledge is necessary to identify site-level exposure and refine technical prioritisation. Stakeholder engagement broadly confirmed the main spatial patterns identified through the technical assessment, while also revealing specific streets, facilities and public spaces where district- or census-level averages do not fully represent local exposure. Healthcare environments, school surroundings, pedestrian routes, poorly shaded streets, and highly paved public spaces were repeatedly identified as priority settings. Technical outputs should therefore be

used as a territorial prioritisation framework and complemented with site-level verification and continued stakeholder engagement.

3.3. Implementation conclusions

Conclusion 6. Future climate scenarios justify early and sustained adaptation action. Current extreme-heat severity was classified as substantial, while future severity remains substantial under the intermediate scenario and becomes critical under the high-emission scenario. Urgency was assessed as more action needed at municipal level, with immediate action required in priority locations and for measures with long implementation periods. Resilience capacity was classified as medium, resulting in a high overall risk priority. This combination shows that adaptation should begin before more severe climatic conditions are reached, particularly where structural measures such as canopy development, Green Infrastructure reinforcement and public-space redesign require several years before delivering their full benefits.

Conclusion 7. Phase 3 must translate the risk assessment into targeted, differentiated and monitorable action. Phase 3 should use the territorial priorities and risk profiles identified in Phase 2 to define opportunity areas, select appropriate Nature-based Solutions and climate-resilient vegetation, assess feasibility and implementation timing, and establish a phased intervention pathway. Measures should be adapted to the main driver of risk in each location: environmental and spatial interventions where exposure is dominant, stronger protection of vulnerable populations where social sensitivity is greater, and integrated responses where both dimensions coincide. The planned digital platform should support implementation and monitoring by integrating risk, vegetation and intervention information and allowing priorities to be reviewed over time.

3.4. Methodological conclusions and remaining challenges

Conclusion 8. Phase 2 provides an improved and reproducible evidence base for municipal decision-making. Phase 2 improved the spatial resolution, transparency, and operational relevance of the Climate Risk Assessment. It integrated local information on Land Surface Temperature, solar exposure, shade, pavements, Urban Green Infrastructure, vegetation condition and resilience, population vulnerability, and stakeholder knowledge. The Environmental Heat Risk Index, Population Vulnerability Index and Socio-environmental Heat Risk Index were implemented through reproducible workflows, providing a traceable connection between the original datasets, intermediate calculations, and final territorial priorities. This represents a substantial refinement of the broader assessment developed in Phase 1 and provides a stronger basis for municipal adaptation planning.

Conclusion 9. Important information and methodological limitations remain and should guide future monitoring. Several limitations remain despite the improvements achieved in Phase 2. Land Surface Temperature does not directly represent air temperature or human thermal comfort, while shade modelling does not fully distinguish between usable pedestrian shade and other forms of physical shade. Vegetation and ecosystem-service estimates rely partly on remote sensing, artificial intelligence, allometric relationships and comparative resilience models and therefore require continued field validation. Important information is also lacking on heat-related health impacts, housing conditions, indoor temperatures, access to cooling, energy poverty, social isolation, outdoor workers, and patterns of public-space use. Participation was also more limited in the smaller settlements and among some vulnerable groups. These gaps should guide future data collection, monitoring, field validation, and stakeholder engagement during Phase 3.

4 Progress evaluation

Phase 2 translated the broad climate-risk characterisation completed in Phase 1 into a detailed local assessment of how extreme heat affects Huércal-Overa. It integrated environmental, territorial, social and participatory evidence to identify priority areas and prepare the adaptation-planning activities foreseen for Phase 3.

The assessment combined Land Surface Temperature, solar exposure, shade, pavements, Urban Green Infrastructure, vegetation condition and resilience, ecosystem services, and population vulnerability across multiple scales, from the municipality and principal settlements to census districts, regular grids, greenspaces, and individual vegetation elements. The resulting environmental and socio-environmental risk maps show where adaptation is most needed, while the complementary analyses explain the main risk drivers in each location. Stakeholder engagement added information on public-space use, sensitive facilities, vulnerable groups, and local hotspots not fully captured by spatial data.

Phase 3 will use these outputs to develop the Urban Naturalisation Strategy for Reducing Heat Risk, translating the identified priorities into strategic objectives, locally adapted guidelines, opportunity areas, and site-specific Nature-based Solutions. It will also assess technical, economic, and operational feasibility, select vegetation suited to future climate and water conditions and establish a phased implementation pathway.

The datasets and indicators generated will also provide the basis for the digital platform for integrated Urban Green Infrastructure and climate-risk management, enabling the Municipality to visualise priorities, consult vegetation or risk data, compare interventions and track implementation.

Actions completed during Phase 2 included Landsat 8 processing for summer 2025, LST and hotspot analysis, solar-exposure and shade modelling, pavement mapping and two field campaigns, high-resolution vegetation detection and validation, green-cover and vigour analysis, climate-resilience and ecosystem-service assessment, population-vulnerability analysis and the integration of environmental and social risk.

Stakeholder actions included a technical meeting with municipal representatives, contact with local organisations, an online survey, a participatory heat map and communication through the project microsite, municipal channels, social media, messaging services, and press releases. As summarised in Table 4-1, the main Phase 2 key performance indicators were achieved. These included completion of the detailed local Climate Risk Assessment, development of the principal environmental and social datasets, assessment of Urban Green Infrastructure, identification of priority areas and establishment of the technical basis for Phase 3. Stakeholder participation was also completed, although with more limited territorial coverage in the smaller settlements.

Table 4-1. Overview of key performance indicators

Key performance indicator	Progress
Completion of the detailed local Climate Risk Assessment	Achieved. Environmental, social, and socio-environmental heat risk were assessed at municipal, settlement, district, and census-section scales.
Development of local environmental and exposure datasets	Achieved. Summer LST, shade, solar exposure, pavements, vegetation structure, green cover, vigour, resilience, and ecosystem-service datasets were produced.

Development of a population-vulnerability assessment	Achieved. Age, income, and education were integrated into a Population Vulnerability Index for the ten census sections analysed.
Identification of environmental and socio-environmental priority areas	Achieved. District 4 and Las Labores were identified as having high environmental risk; District 4 and all six principal settlements had high socio-environmental risk.
Assessment of Urban Green Infrastructure	Achieved. A high-resolution vegetation inventory and analyses of canopy coverage, diversity, condition, resilience, and thermal-regulation capacity were completed.
Stakeholder participation and local validation	Achieved with limitations. One technical session, an online survey and a participatory map were completed, generating 55 georeferenced contributions. Participation was stronger in the main urban centre than in the smaller settlements.
Communication and dissemination of the project	Achieved. The project was communicated through the microsite, One Pager, municipal website, social media, WhatsApp, and press releases.
Definition of the technical basis for Phase 3	Achieved. Priority areas, risk drivers, intervention needs and the methodological basis for the Naturalisation Strategy and digital platform were established.

Table 4-2 summarises progress against the main project milestones, from data compilation and local heat, Green Infrastructure and vulnerability analyses to the integration of environmental and social risk, completion of the Key Risk Assessment and definition of the Phase 3 work plan.

Table 4-2. Overview of milestones

Milestone	Progress
Phase 2 environmental and social data collection completed	Achieved. Satellite, municipal, statistical, field, and participatory data were compiled and processed.
Local extreme-heat analysis completed	Achieved. Persistent thermal patterns, hotspots, land-use relationships, solar exposure, and shade conditions were characterised.
Urban Green Infrastructure assessment completed	Achieved. Vegetation distribution, coverage, diversity, vigour, resilience, biometrics, and ecosystem services were evaluated.
Environmental Heat Risk Index completed	Achieved. LST, tree-canopy deficit and total-shade deficit were integrated for the urban districts and principal settlements.
Population Vulnerability Index completed	Achieved. Demographic, economic, and educational vulnerability were combined into a common territorial indicator.
Socio-environmental Heat Risk Index completed	Achieved. Environmental and population-vulnerability results were integrated to establish final territorial priorities.
Key Risk Assessment completed	Achieved. Current and future severity, urgency, resilience capacity, and overall risk priority were assessed.
Stakeholder consultation and validation completed	Achieved with partial territorial coverage. Municipal and citizen input was incorporated, although further engagement is required in the smaller settlements and with some vulnerable groups.
Phase 3 work plan defined	Achieved. The planned Naturalisation Strategy, opportunity-area assessment, Nature-based Solutions, vegetation selection, feasibility analysis, and digital platform were specified.

Together, Tables 4-1 and 4-2 confirm that Phase 2 achieved its main analytical objectives and milestones, with stakeholder coverage in the smaller settlements remaining the principal limitation to be addressed in Phase 3.

5 Supporting documentation

- Main Report (PDF)

Visual Outputs (infographics, maps, charts)	
Environmental risk associated with urban heat	Figure 57 environmental risk.png; Figure 58 environmental risk municipality.png
Shade analysis	Figure 8 urban shade Huercal-Overa.png; el_saltador_shadow_average_summer.tif; la_hoya_shadow_average_summer.tif; las_labores_shadow_average_summer.tif; san_francisco_shadow_average_summer.tif; stmaria_nieva_shadow_average_summer.tif; urbano_reducido_shadow_average_summer.tif; urcal_shadow_average_summer.tif
Social parameters and climatic vulnerability	Figure 59 socio environmental risk.png; Figure 60 socio environmental risk municipality.png
Socioeconomic analysis and population vulnerability	Figure 39 age related vulnerability.png; Figure 40 economic vulnerability.png; Figure 41 educational vulnerability.png; Figure 42 population vulnerability.png; Figure 43 population vulnerability municipality.png
Urban configuration and heatwaves	lst_summer_mean.tif
- Urban analysis	cover/use_group_lst_[aug/jul/jun/sep/summer]_mean_[boxplot/dunn_heatmap].png
- census sections	codes: 0405301001; 0405302001; 0405302002; 0405302003; 0405303002; 0405303003; 0405303004; 0405304001; 0405304002; 0405305002; per code: cover_group_lst_[aug/jul/jun/sep]_mean_dunn.png; use_group_lst_[aug/jul/jun/sep/summer]_mean_dunn.png; unified_histograms.png; general: census_section_[cover/use]_group_distribution.png; census_section_municipal_delta.png; census_section_quintiles.png; census_section_summer_lst.png; lst_summer_mean_[getis_ord/lisa].png; map_lst_summer.png; monthly_temperatures.png; raster_[august/july/june/overall_summer/september/summer].png; thermal_comparison_[codes].png
- municipality	lst_[aug/jul/jun/sep/summer]_mean_[getis_ord/lisa].png; municipality_[cover/use]_group_distribution.png; municipality_[cover/use]_group_lst_[aug/jul/jun/sep/summer]_mean_[dunn/half_violin_boxplot].png; municipality_unified_histograms.png; raster_[august/july/june/overall_summer/september/summer].png; thermal_comparison_municipality.png
- sections	lst_[aug/jul/jun/sep/summer]_mean_[getis_ord/lisa].png; raster_[august/july/june/overall_summer/september/summer].png; sections_cover_group_distribution.png; sections_source_lst_[aug/jul/jun/sep]_mean_half_violin_boxplot.png; sections_unified_histograms.png; sections_use_group_distribution.png; sections_use_group_lst_[aug/jul/jun/sep]_mean_dunn.png; thermal_comparison_[el_saltador/la_hoya/las_labores/san_francisco/st_maria_nieva/urban_area_limit/urcal].png
Urban Green Infrastructure and heatwaves	
- Ecosystem Services	Figure 13 tree density.png; Figure 16 relative humidity increase by tree canopy.png; Figure 17 total radiation reduction by tree canopy.png; Figure 18 radiation reduction by tree canopy.png; Figure 19 CO2 absorption by tree canopy.png; Figure 20 ecosystem services Huercal-Overa.png; Figure 21-27 ecosystem services District 1-7 HO.png; Figure 28-33 ecosystem services [El Saltador/La Hoya/Las Labores/San Francisco/Santa María de Nieva/Úrcal].png
- Green Areas Analysis	Figure 11 type of green cover.png; Green areas_unified_histograms.png; [boxplot/histogram/kde/map]_[aug/jul/jun/sep/summer].png
- LST and Green Infrastructure	Figure 37 LST and tree canopy cover.png; Figure 38 LST and tree canopy cover settlements.png; LST summer mean.tif
- Resilience	Figure 14 severe tree risk.png; Figure 15 critical tree risk.png
- Vegetal Inventory and related parameters	Figure 11 type of green cover.png

Communication and participation outputs	
Communication	1ª COMUNICACIÓN RRSS; 2ª COMUNICACIÓN RRSS; 3ª COMUNICACIÓN RRSS; 4ª COMUNICACIÓN RRSS; Contenido Microsite; Huércal-Overa impulsa la Fase II del proyecto LUGIA para combatir las olas de calor urbanas - Esradio Almería; Huércal-Overa participa en un proyecto Climaax para hacer frente a las olas de calor - Almeria Noticias; Huércal-Overa, único municipio español en un proyecto Climaax para hacer frente a las olas de calor - La Voz de Almería; One Pager_LUGIA; Un proyecto único en España estudia olas de calor en Almería - Diario de Almería; Un pueblo de Almería, pionero para llevar a cabo un proyecto contra las olas de calor - Diario de Almería
Participation	Encuesta Enlace; INFORME_participacion_mapa_calor; PARTICIPACION_mapa_calor_resultados; PARTICIPACION_visor_herramienta; Presentación Resultados Fase I LUGIA

Datasets collected	
census and district geometries	census_urban_geometries.gpkg
workflows	01_Environmental_Heat_Risk_Index_Workflow.ipynb; 02_Population_Vulnerability_Index_Workflow.ipynb;

	03_Socioenvironmental_Heat_Risk_Index_Workflow.ipynb; README.md; requirements.txt; inputs/; outputs/
urban green infrastructure and heatwaves	'ndvi_savi_complemetary vegetation.gpkg'; 'tree inventory_100x100 grid.gpkg'; 'tree inventory.gpkg'
- vegetal inventory and related parameters	
- resilience	'tree inventory.gpkg'; 'tree inventory_100x100 grid.gpkg'
- lst and green infrastructure	tree inventory.gpkg
- green_areas_analysis	statistics_aug.csv; statistics_jul.csv; statistics_jun.csv; statistics_sep.csv; statistics_summer.csv
- tables	
- green_areas_analysis	green_areas_buffers.gpkg; green_areas_lst_aug_mean_summary.csv;
- thermal_eda	green_areas_lst_jun_mean_summary.csv; green_areas_lst_summer_mean_summary.csv;
- tables	green_areas_lst_jul_mean_summary.csv; green_areas_lst_sep_mean_summary.csv
- ecosystem services	tree inventory.gpkg; tree inventory_100x100 grid.gpkg
pavements in relation to urban heat	pavement_reflectance_matrix_huercal_overa.xlsx
environmental risk associated with urban heat	ho socio environmental risk.gpkg; settlements socio environmental risk.gpkg; lst_summer_mean.tif
shade analysis	shadows 100x100 grid.gpkg; solar exposure/ el_saltador_, la_hoya_, las_labores_, san_francisco_, stmaria_nieva_, urbano_reducido_, urcal_shadow_average_summer.tif
socioeconomic analysis and population vulnerability	ho socio environmental risk.gpkg; settlements socio environmental risk.gpkg; INE source tables/ 30842.csv; 66637.csv; 69109.csv
- vulnerability index analysis	age_vulnerability_census_sections.csv; census_sections_utm_vulnerability.gpkg; cover_use_census_sections_semantic_a.gpkg; cover_use_census_sections_semantic_a_utm.gpkg; education_vulnerability_census_sections.csv; exposure_index_census_sections.csv; final_vulnerability_index_census_sections.csv; income_vulnerability_census_sections.csv; sensitivity_index_census_sections.csv; utm_vulnerability_grid.gpkg
social parameters and climatic vulnerability	ho socio environmental risk.gpkg; settlements socio environmental risk.gpkg
urban configuration and heatwaves	group_lst_mean_chi2.csv; group_lst_mean_ks.csv; group_lst_mean_woe_iv.csv
- census_sections	
- advanced_correlation	
- census_sections	categorical_correlation_summary.csv; cover_group_lst_mean_thermal_table.csv;
- categorical_correlation	use_group_lst_mean_thermal_table.csv
- census_sections	census_section_results.gpkg
- census_section_analysis	
- census_sections	aug_mean_lst_ranking.csv; cover_distribution.csv; jul_mean_lst_ranking.csv;
- census_section_analysis	jun_mean_lst_ranking.csv; sep_mean_lst_ranking.csv; statistics_lst.csv;
- tables	summary_census_sections.csv; summer_mean_lst_ranking.csv; use_distribution.csv
- census_sections	tables__cover_group_lst_mean_dunn.csv; tables__group_lst_mean_kruskal.csv;
- inferential_correlation	tables__use_group_lst_mean_dunn.csv
- census_sections	0405301001_autocorrelation.gpkg; 0405302001_autocorrelation.gpkg;
- spatial_autocorrelation	0405302002_autocorrelation.gpkg; 0405302003_autocorrelation.gpkg; 0405303002_autocorrelation.gpkg; 0405303003_autocorrelation.gpkg; 0405303004_autocorrelation.gpkg; 0405304001_autocorrelation.gpkg; 0405304002_autocorrelation.gpkg; 0405305002_autocorrelation.gpkg; tables.csv
- census_sections	tables__count_summary.csv; tables__cover_group_lst_mean_advanced_summary.csv;
- thermal_eda	tables__group_summary.csv; tables__thermal_ranking.csv;
- municipality	tables__use_group_lst_mean_advanced_summary.csv advanced_correlation__group_lst_mean_chi2.csv; advanced_correlation__group_lst_mean_ks.csv; advanced_correlation__group_lst_mean_woe_iv.csv; categorical_correlation__categorical_correlation_summary.csv; categorical_correlation__cover_group_lst_mean_thermal_table.csv; categorical_correlation__use_group_lst_mean_thermal_table.csv; spatial_autocorrelation_results.gpkg
- municipality	tables__municipality__group_lst_mean_kruskal.csv;
- inferential_correlation	tables__municipality_cover_group_lst_mean_dunn.csv; tables__municipality_use_group_lst_mean_dunn.csv
- municipality	tables.csv
- spatial_autocorrelation	
- municipality	tables__municipality__group_summary.csv; tables__municipality_count_summary.csv;
- thermal_eda	tables__municipality_cover_group_lst_mean_advanced_summary.csv; tables__municipality_thermal_ranking.csv; tables__municipality_use_group_lst_mean_advanced_summary.csv
- sections	advanced_correlation__group_lst_mean_chi2.csv; advanced_correlation__group_lst_mean_ks.csv; advanced_correlation__group_lst_mean_woe_iv.csv; categorical_correlation__categorical_correlation_summary.csv; categorical_correlation__cover_group_lst_mean_thermal_table.csv; categorical_correlation__use_group_lst_mean_thermal_table.csv; spatial_autocorrelation_results.gpkg
- sections	tables__sections__group_lst_mean_kruskal.csv; tables__sections_cover_group_lst_mean_dunn.csv;
- inferential_correlation	tables__sections_use_group_lst_mean_dunn.csv
- sections	tables.csv
- spatial_autocorrelation	
- sections	tables__sections__summary.csv; tables__sections_count_summary.csv;
- thermal_eda	tables__sections_cover_group_lst_mean_advanced_summary.csv;

- urban_analysis	tables__sections_source_lst_mean_advanced_summary.csv; tables__sections_thermal_ranking.csv; tables__sections_use_group_lst_mean_advanced_summary.csv tables__cover_group_lst_mean_dunn.csv; tables__cover_group_lst_mean_thermal_table.csv; tables__group_lst_mean_kruskal.csv; tables__use_group_lst_mean_dunn.csv; tables__use_group_lst_mean_thermal_table.csv

6 References

AEMET (n.d.). Climate projections for the XXI Century. Agencia Estatal de Meteorología, Gobierno de España.

AdapteCCa (n.d.). AdapteCCa Climate Change Scenario Viewer. Spanish Climate Change Adaptation Platform, Oficina Española de Cambio Climático, AEMET and Fundación Biodiversidad, with the collaboration of CSIC.

Bao, J., Li, X. & Yu, C. (2015). *The Construction and Validation of the Heat Vulnerability Index, a Review*. *International Journal of Environmental Research and Public Health*, 12(7), 7220–7234. https://doi.org/10.3390/ijerph120707220.

Bowler, D. E., Buyung-Ali, L., Knight, T. M. & Pullin, A. S. (2010). *Urban greening to cool towns and cities: A systematic review of the empirical evidence*. *Landscape and Urban Planning*, 97(3), 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006.

CLIMAAX (2026). CLIMAAX CRA Handbook. Climate Risk and Vulnerability Assessment Framework and Toolbox.

Copernicus Climate Change Service (2024). Copernicus Interactive Climate Atlas: climate projections and indicators for Europe. European Centre for Medium-Range Weather Forecasts.

European Commission (2019). The European Green Deal. COM (2019) 640 final. European Commission.

European Commission (2021). Forging a climate-resilient Europe – the new EU Strategy on Adaptation to Climate Change. COM(2021) 82 final. European Commission.

Instituto Nacional de Estadística (INE) (2025). *Censo anual de población / Padrón continuo: población por edad a nivel de sección censal.* Instituto Nacional de Estadística, Spain.

Instituto Nacional de Estadística (INE) (2023). *Atlas de Distribución de Renta de los Hogares: renta neta media por persona.* Instituto Nacional de Estadística, Spain.

Instituto Nacional de Estadística (INE) (2024). *Censo anual de población: educación y relación con la actividad.* Instituto Nacional de Estadística, Spain.

Junta de Andalucía (2021). Plan Andaluz de Acción por el Clima 2021–2030. Junta de Andalucía.

Ministerio para la Transición Ecológica y el Reto Demográfico (2021). Plan Nacional de Adaptación al Cambio Climático 2021–2030. Oficina Española de Cambio Climático, MITECO.

Municipality of Huércal-Overa (2020). General Urban Development Plan. Ayuntamiento de Huércal-Overa.

Municipality of Huércal-Overa (2022). Huércal-Overa 2030 Urban Agenda: Local Strategy for Sustainable Development and Climate Adaptation. Ayuntamiento de Huércal-Overa.

Municipality of Huércal-Overa and CESYT (2025). LUGIA Deliverable Phase 1: Climate Risk Assessment. CLIMAAX Project.

Nasrollahi, N., Ghosouri, A., Khodakarami, J. & Taleghani, M. (2020). *Heat-Mitigation Strategies to Improve Pedestrian Thermal Comfort in Urban Environments: A Review*. *Sustainability*, 12(23), 10000. https://doi.org/10.3390/su122310000.

Nicholson, S., Nikolopoulou, M., Watkins, R., Löve, M. & Ratti, C. (2024). *Data driven design for urban street shading: Validation and application of Ladybug Tools as a design tool for outdoor thermal comfort*. *Urban Climate*, 56, 102041. https://doi.org/10.1016/j.uclim.2024.102041.

Osberghaus, D. & Abeling, T. (2022). *Heat vulnerability and adaptation of low-income households in Germany*. *Global Environmental Change*, 72, 102446. https://doi.org/10.1016/j.gloenvcha.2021.102446.

Rahman, M. A., Moser, A., Rötzer, T. & Pauleit, S. (2019). *Comparing the transpirational and shading effects of two contrasting urban tree species*. *Urban Ecosystems*, 22(4), 683–697. https://doi.org/10.1007/s11252-019-00853-x.

Reid, C. E., O'Neill, M. S., Gronlund, C. J., Brines, S. J., Brown, D. G., Diez-Roux, A. V. & Schwartz, J. (2009). *Mapping Community Determinants of Heat Vulnerability*. *Environmental Health Perspectives*, 117(11), 1730–1736. https://doi.org/10.1289/ehp.0900683.

World Health Organization (2026). *Heat and health*. WHO Fact Sheet, 31 July 2026.

Zhou, D., Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., Frolking, S., Yao, R., Qiao, Z. & Sobrino, J. A. (2019). *Satellite Remote Sensing of Surface Urban Heat Islands: Progress, Challenges, and Perspectives*. *Remote Sensing*, 11(1), 48. https://doi.org/10.3390/rs11010048.