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O.2.1 – Climate Adaptation Plans (CAPs) for UNESCO SITES

Executive Summary

Municipality of Monte Sant'Angelo

UNESCO World Heritage Site – Sanctuary of Saint Michael the Archangel

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Climate Adaptation Plan for the UNESCO World Heritage Site Sanctuary of San Michele Arcangelo – Monte Sant'Angelo

Interreg Italy–Croatia CAMPUS – Climate Adaptation Plans for UNESCO Sites

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Municipality of Monte Sant'Angelo
UNESCO World Heritage Site: Sanctuary of San Michele Arcangelo

1. Summary at a glance

The Climate Adaptation Plan (CAP) is the strategic framework through which the Municipality of Monte Sant'Angelo addresses climate-related risks affecting the Sanctuary of San Michele Arcangelo, its UNESCO buffer zone and the wider historic urban system. The Plan is developed within the Interreg Italy–Croatia CAMPUS project and is designed to integrate climate adaptation and mitigation into the management of the World Heritage Site, with the 2030 horizon as the main operational milestone and a longer trajectory towards 2050.

The CAP is not framed as an emergency-only document. It combines risk assessment, preventive conservation, public-space adaptation, energy efficiency, monitoring, stakeholder participation and governance. Its core purpose is to preserve the Outstanding Universal Value (OUV) of the Sanctuary while improving the resilience, safety and sustainability of the site experience for residents, pilgrims and visitors.

Executive item	Main message
Strategic focus	Protect the OUV of the Sanctuary and its buffer zone through an integrated adaptation and mitigation framework.
Main risk profile	Very high priority: heat waves; intense rainfall and urban runoff. High priority: humidity and hypogeal microclimate imbalance; drought and water stress. Medium-high priority: strong wind and storms, light pollution, territorial fire risk, climate-sensitive tourism pressure.
Method	Multi-risk and multi-level approach, combining technical-scientific analysis, Living Labs and regulatory compatibility with heritage protection rules.
Action structure	Four strategic pillars, four priority intervention areas and 22 actions covering monitoring, adaptation, mitigation, governance, education and institutional integration.
Monitoring system	Baseline 2025 effectiveness indicators and 1991–2020 climate context indicators, with intermediate review in 2028 and final review in 2031.

2. Site and planning context

The Sanctuary of San Michele Arcangelo is one of the seven components of the serial World Heritage property "Longobards in Italy. Places of the Power (568–774 A.D.)", inscribed in 2011 under criteria (ii), (iii) and (vi). Within this serial property, Monte Sant'Angelo is defined by the exceptional spiritual and pilgrimage role of the micaelic cult, the natural cave around which the sanctuary is organised, and the layered architectural, decorative and epigraphic heritage associated with the site.

The CAP treats the UNESCO property as a system rather than a single monument. The core zone covers 0.31 hectares and coincides with the Sanctuary complex. The buffer zone covers 16.82 hectares and includes the historic centre, the Cittadella Micaelica, the complexes of San Pietro, the Baptistery of San Giovanni in Tumba / Tomba di Rotari, the Church of Santa Maria Maggiore and the area around the Castle. This means that adaptation must address not only the cave and the sanctuary fabric, but also access routes, public spaces, lighting, drainage, visitor flows, perceived quality and the wider urban setting.

Dimension	Executive interpretation
OUV attributes	Natural cave, access stairway, presbytery, crypts, Angevin nave, bell tower, frescoes, graffiti, roofs, bronze doors, San Pietro complex, Baptistery, buffer-zone historic buildings, and the intangible pilgrimage practice.
Main sensitivities	Hypogeal microclimate, limestone/calcarenite materials, frescoes and historical surfaces exposed to humidity, salt crystallisation, biodeterioration, driving rain, wind and wet-dry cycles.
Planning integration	The CAP complements the UNESCO Management Plan 2022–2027, with a specific climate dimension, and is designed to be integrated into the future PAESC and the PUG process.

3. Climate evidence and risk profile

The CAP identifies Monte Sant'Angelo as a site with a distinctive local climate: hill-mountain position, proximity to the sea, altitude around 843 m a.s.l., exposure to wind and rapid weather changes. The altitude partly mitigates summer thermal stress compared with lowland areas, but does not eliminate the effects of warming, heat waves, irregular rainfall and hydrometeorological extremes.

Evidence area	CAP evidence
Temperature baseline	Mean annual temperature of 12.5 °C in 1991–2020; absolute minimum −9 °C in 2012; absolute maximum 38.8 °C in 2000; annual thermal anomalies indicate a clear warming signal.
Rainfall variability	Maximum daily rainfall of 141 mm in 2014; 2014 as the wettest year with 878.6 mm; 2019 as the driest year with 347.6 mm.
Wind exposure	Maximum wind speed of 26 m/s recorded in 2010, from the CAMPUS analysis of the Monte Sant'Angelo station over 2010–2024; prevailing directions from NE and E; gusts above 20 m/s recorded almost every year in the last fifteen years.
Future signals	General warming, up to +2 °C over 2021–2050 under RCP8.5 and +3/+4 °C over 2071–2100 under RCP4.5, with summer peaks up to +8 °C under RCP8.5. Reduction of total and particularly summer precipitation, down to −60% in southern Italy under RCP4.5. Increase of maximum daily precipitation, reaching 75–85 mm at many points of the Gargano in the worst-case scenario, and of consecutive dry days. Rising Mediterranean fire risk, identified by the IPCC as one of the main climate change effects in the area.

Priority follows the probability × impact product on a 1–25 scale, with thresholds of 21–25 for very high, 16–20 for high, 10–15 for medium-high, 5–9 for medium and 1–4 for low. Each risk carries a confidence level reflecting the availability and robustness of the supporting data. Expert judgement and the outcome of the participatory process may justify a one-level shift from the calculated value.

Risk	Priority	Executive implication
Heat extremes and heat waves	Very high (P5 × I5, high confidence)	Thermal discomfort, pressure on public space and events, higher energy demand, and possible changes in internal microclimatic cycles.
Intense rainfall and urban runoff	Very high (P5 × I5, high confidence)	Rapid runoff, local erosion, drainage overload, infiltrations and local instability in a steep historic urban context.

Risk	Priority	Executive implication
Humidity and Sanctuary microclimate imbalance	High (P5 × I4, medium confidence)	Condensation, biological growth, salt crystallisation and degradation of frescoes and other hypogeal surfaces.
Drought and water stress	High (P4 × I4, high confidence)	Long dry periods, water management pressure, vegetation stress and indirect fire-risk implications.
Strong wind and storms	Medium-high (P3 × I4, medium confidence)	Driving rain, abrasion, stress on façades, roofs, projecting elements and envelope components.
Light pollution	Medium-high (P5 × I3, high confidence)	Structural issue for buffer-zone quality, night-time perception and the pilot action.
Territorial fire risk	Medium-high (P3 × I4, medium confidence)	Induced by the Gargano National Park context, with indirect impacts on accessibility, air quality and landscape.
Climate-sensitive tourism pressure	Medium-high (P5 × I3, medium confidence)	Multiplier of climate risks during summer peaks and religious festivity days, with implications for visitor management and peak-season use.

4. Expected impacts on heritage conservation and site use

The CAP interprets climate risk through impact chains that connect climate drivers, exposed elements and management consequences. For the Sanctuary, the most critical chains are those combining heat, humidity, rainfall, wind and visitor pressure with the cave microclimate, porous stone materials, frescoes, graffiti, external stone surfaces and urban public spaces.

Impact area	Executive summary
Materials and surfaces	Temperature and relative-humidity oscillations may intensify wet-dry cycles, salt crystallisation, biodeterioration, joint alteration and surface decohesion. External limestone/calcarenite surfaces are exposed to driving rain, wind, particulate deposition and pollutant interactions.
Frescoes and hypogeal environments	Persistent humidity, evaporation-condensation dynamics, migration and recrystallisation of soluble salts and biodeterioration are key conservation concerns. The COVID-period closure, when reduced ventilation coincided with mould and biological colonisation, is treated in the CAP as direct evidence of microclimatic sensitivity.
Water and runoff	The steep and mineral historic centre may experience rapid runoff, local flooding, infiltration into masonry and stress on drainage systems during intense rainfall. The CAP therefore treats drainage mapping and preventive maintenance as core adaptation needs.
Wind and driving rain	Wind is treated not only as a mechanical load but as a driver of moisture penetration, abrasion, pollutant transport and accelerated decay of exposed carbonate materials.
Comfort and use	The combination of warmer conditions, mineral paving, limited shade and concentrated pilgrim/tourist flows may affect comfort, accessibility, safety and energy demand, especially in spring-summer and during devotional peaks.

5. Participatory process and stakeholder evidence

The CAP is grounded in the CAMPUS Living Lab methodology, based on the quadruple helix model: public institutions, research, economic actors and the local community. In Monte Sant'Angelo, three Living Labs progressively moved from shared problem framing to risk assessment and then to the co-validation of implementable countermeasures.

Date	Step	Contribution to the CAP
26 June 2025	First Living Lab	Shared construction of the climate problem; community perception of climate change; water, agriculture and ecosystems; first set of community-proposed solutions.
28 October 2025	Second Living Lab	Multi-risk analysis by IUAV; abacus of Grey, Green and Soft measures; evidence on existing interventions and microclimate issues from the Sanctuary technical reference.
16 January 2026	Third Living Lab	Co-validation of three countermeasures: sustainable lighting redevelopment, photovoltaic system on Casa del Pellegrino / ancillary buildings, and green areas/tree planting in access spaces; discussion of the cross-border monitoring tool.

Stakeholder requests were translated into CAP actions: microclimatic monitoring and visitor management for the Sanctuary managers; compatibility and reversibility criteria for the Soprintendenza; public-space quality and comfort for guides, operators and citizens; education and awareness for schools and associations; integration with PUG and PAESC for the Municipality.

6. Strategy and action framework

The CAP general objective is to conserve the OUV of the Sanctuary and its heritage system by strengthening climate resilience of the property, the buffer zone and the urban access system through integrated adaptation and mitigation measures. The strategy is organised through five specific objectives: climate risk assessment, climate adaptation, climate mitigation, knowledge sharing and capacity building, and integrated governance.

Strategic pillar	Main actions
P1 – Knowledge and monitoring	Microclimatic monitoring inside the Sanctuary; lighting-energy census; runoff and drainage mapping; cross-border CAMPUS monitoring tool; high-resolution local weather station.
P2 – Adaptation of the property and buffer zone	Pilot lighting redevelopment; programmed maintenance of roofs and gutters; visitor management in hot/devotional peaks; compatible shading and urban furniture; drainage adaptation; programmed conservation of frescoes; green areas and tree planting.
P3 – Mitigation and energy sustainability	Energy efficiency in public buildings in the historic centre; feasibility studies for renewable energy compatible with heritage protection; photovoltaic system on Casa del Pellegrino after feasibility assessment.
P4 – Governance, communication and capacity building	Permanent climate governance table; climate education for schools; information materials for tourists and pilgrims; UNESCO climate network participation; emergency-plan update; formal integration of the CAP into PAESC and PUG.

Priority area	Scale	Strategic response
Sanctuary complex	Architectural and hypogeal asset	Microclimatic monitoring, protection of

Priority area	Scale	Strategic response
		conservation features and visitor-flow management.
Buffer zone / historic centre	Urban-monumental system	Lighting redevelopment, drainage maintenance, public-space comfort and light-pollution control.
Access and mobility system	Territorial connections	Sustainable mobility, protection of pilgrimage routes and shading.
Gargano territorial context	Wider territorial system	Coordination with the Gargano National Park and Civil Protection on drought, fire and landslide-related risks.

7. Monitoring system and Baseline 2025

The CAP monitoring system has three levels: implementation monitoring of actions, effectiveness monitoring by strategic pillar, and climate-context monitoring. The 2025 baseline annex is the operational tool supporting the effectiveness monitoring of the Plan. It is structured around 16 effectiveness indicators and 6 climate-context indicators. The intermediate review is planned in 2028, while the final review is planned in 2031.

Baseline interpretation

Values marked as "to be measured" depend on monitoring actions that have not yet been activated, especially within Pillar 1. Energy estimates for the pilot lighting area are parametric until the light-point census and energy diagnosis under CAP.1.2 are completed. Indicators C-02 and C-03 are based on the Amendola station and are proxies at provincial scale, not local measurements of the historic centre of Monte Sant'Angelo at 843 m a.s.l., as stated in Annex B of the CAP. The baseline value of indicator C-05 comes from the CAMPUS series of the Monte Sant'Angelo station over 2010–2024, not from the 1991–2020 SCIA series. Indicator P3-01 refers to action CAP.2.1, which belongs to Pillar 2, and is reported under Pillar 3 because the effect it measures is a mitigation effect.

Effectiveness indicators – Baseline 2025 and expected 2030 trends

ID	Indicator	Baseline 2025	Expected result / trend 2030
P1-01	Active microclimatic sensors in the Sanctuary (T, RH, CO_2, surface) – CAP.1.1	0	At least 6 active sensors by 2027
P1-02	High-resolution local weather station in the buffer zone – CAP.1.5	Absent	Operational, with an annual dataset, by 2028
P1-03	Technical mapping of critical runoff and drainage points in the buffer zone – CAP.1.3	Not available	Cartography and technical sheets completed by 2027
P1-04	Integration of MSA data into the CAMPUS cross-border Monitoring Tool (O1.1) – CAP.1.4	Partial integration	Use of indicators from the relevant sections of the Monitoring Tool
P2-01	Programmed maintenance of Sanctuary roofs and gutters – CAP.2.2	Not tracked	At least 2 documented interventions in 2026–2030
P2-02	Shaded and green surface in access areas and public spaces – CAP.2.4, CAP.2.7	0 sqm (first mapping to be carried out)	Increasing compared with the first mapping
P2-03	Intense weather events managed without documented conservation damage	Not monitored	100% of tracked events
P2-04	Programmed conservation plan for hypogeal frescoes – CAP.2.6	Absent	Plan adopted and at least 1 degradation-monitoring cycle completed
P3-01	Light points redeveloped in the pilot area – CAP.2.1	0	100% of pilot-area light points by 2027
P3-02	Energy saving in the pilot area	To be measured through the census	At least −32% (GSE benchmark), to

ID	Indicator	Baseline 2025	Expected result / trend 2030
		(CAP.1.2)	be replaced with real data
P3-03	Avoided CO_2 emissions from the pilot area	0	Consistent with achieved energy savings
P3-04	Renewable-energy feasibility study and photovoltaic plant on Casa del Pellegrino – CAP.3.3, CAP.3.4	Not started	Study completed; plant sized after the study
P4-01	Climate governance table meetings – CAP.4.1	0	At least 2 meetings/year, with annual progress report
P4-02	Integration of the CAP into the PUG under preparation and the future PAESC – CAP.4.6	Not incorporated	Formal incorporation into the planning instruments
P4-03	Climate education and awareness initiatives carried out – CAP.4.2, CAP.4.3	0	At least 10 initiatives in 2026–2030
P4-04	Community climate-risk perception (periodic survey)	First survey 2025–2026	Increased awareness between survey editions

Climate-context indicators – Baseline 1991–2020

ID	Indicator	Unit	Baseline value	Monitoring approach
C-01	Mean annual temperature	°C	12.5	Annual measurement and comparison with the baseline
C-02	Tropical nights (Tmin > 20 °C)	n/year	Increasing (Amendola reference)	Monitoring and attention threshold
C-03	Summer days (Tmax > 25 °C)	n/year	Increasing (Amendola reference)	Annual monitoring
C-04	Maximum daily precipitation (RX1day)	mm	141 (maximum of the period, 2014)	Monitoring and activation of emergency protocols
C-05	Wind, maximum speed	m/s	26 (2010)	Annual monitoring
C-06	Internal Sanctuary microclimatic parameters (T, RH, dew point, CO_2)	various	To be measured (CAP.1.1)	Continuous monitoring

8. Governance, update cycle and financing logic

Governance is organised on three levels. Locally, the Municipality establishes a permanent climate governance table for the UNESCO site. The table includes the Municipality, the Order of the Fathers of San Michele, the Soprintendenza, the Gargano National Park, the Diocese, Italia Langobardorum, tourism operators and guides, community representatives and schools. It meets at least twice a year and produces an annual CAP progress report.

At regional and national level, the Municipality coordinates with the Region of Puglia on climate and Civil Protection dimensions, with the Ministry of Culture on heritage protection, and with the Ministry for the Environment and Energy Security on the climate dimension. At international level, the CAP is designed to maintain continuity with the CAMPUS partnership and the UNESCO climate-action network after project closure.

The CAP is subject to triennial review, with possible early review after extreme climate events that significantly alter the risk framework, or following updates of the UNESCO Management Plan. Financing is presented as a reasoned map rather than a binding financial plan. The main national lever is Law 77/2006, the instrument dedicated to Italian World Heritage cultural sites, complemented by MiC funds and by the CEI 8xmille allocation for ecclesiastical cultural heritage, a pertinent channel given the ecclesiastical ownership of the Sanctuary. Further sources include the World Heritage Fund and other UNESCO opportunities, MASE, the Italian Climate

Fund, PNACC and FSC channels, LIFE, Horizon Europe, Interreg, PR Puglia FESR-FSE+, CSR Puglia, PAESC support tools, Art Bonus, donations, crowdfunding and Renewable Energy Communities. Three qualifications apply. The MASE lines dedicated to natural World Heritage sites are not relevant to Monte Sant'Angelo, which is a cultural property. Art Bonus is directly usable for the municipally owned public spaces of the buffer zone, while its applicability to the Sanctuary complex must be verified case by case, since the scheme presupposes public ownership or public management or concession. For Renewable Energy Communities the available lever is the GSE feed-in premium, since the PNRR grant is reserved for municipalities below 5,000 inhabitants, a threshold Monte Sant'Angelo exceeds.

9. Part VI pilot action: lighting redevelopment of the buffer zone

The CAP identifies the lighting redevelopment of the external areas of the Sanctuary within the UNESCO buffer zone as the CAMPUS pilot action for Monte Sant'Angelo, under the light infrastructure solutions category of activity A.3.3. The action is framed as an integrated adaptation-mitigation measure: reducing energy consumption and CO_2 emissions while improving evening comfort, public-space quality, safety perception, light-pollution control and the visual hierarchy of the heritage setting.

Pilot-action element	Content of the pilot-action framework
Proposed perimeter	External areas of the Sanctuary within the buffer zone: the square in front of the Basilica, perspective access axes, stairways and historic paved sections near the monumental complex. The perimeter is consolidated at executive design stage, consistently with the framework of protection constraints and with the outcome of the light-point census.
Technical components	LED high-efficiency luminaires, remote control, dimming, smart metering, light-pollution control and ante-operam baseline documentation.
Heritage compatibility criteria	Compatible design, reversibility, use of existing technological routes where possible, and co-design with the Soprintendenza from feasibility stage to final inspection.
Authorisation framework	Landscape authorisation under Art. 146 of Legislative Decree 42/2004; possible architectural authorisation where listed assets are involved; certified notice of commencement of works, with the building procedural requirements set out at executive design stage together with the final perimeter and the technical choices.

Expected impacts of implementation: parametric scenarios

The expected energy and climate impacts are presented as parametric scenarios, built on the GSE benchmark for the LED retrofit of public lighting, which estimates a saving of about 32%, equal to an average of some 133.5 kWh/year per light point, and on an average Italian grid emission factor of 0.28 $kgCO_2$/kWh. The scenarios are prudential and are consolidated with the measured values produced by the light-point census and energy diagnosis under CAP.1.2.

Parametric scenario (possible solution)	Estimated energy saving	Estimated CO_2 reduction
20 light points, LED only	ca. 2.7 MWh/year	ca. 0.76 tCO_2/year
40 light points, LED + dimming 45%	ca. 7.5 MWh/year (average)	ca. 2.10 tCO_2/year
60 light points, LED + dimming 45%	ca. 11.3 MWh/year (average)	ca. 3.17 tCO_2/year

Timing	Phase	Output
Q2 2026	Census and diagnosis	Light-point database; energy and lighting baseline report.
Q2–Q3 2026	Feasibility and design	CAM-compliant executive design and Soprintendenza opinion.
Q3 2026	CAMPUS closure phase	Final CAMPUS report and integration into the cross-border platform.
2026–2027	Implementation	Works, smart metering, telecontrol and functional testing.
2027 onward	Post-operam monitoring	Annual reporting and KPI update.

10. Executive conclusions

The CAP positions climate adaptation as an operational component of heritage management for the Sanctuary of San Michele Arcangelo. Its added value lies in the combination of engineering-oriented risk analysis, preventive conservation, public-space adaptation, energy efficiency and participatory governance. The Plan identifies where the site is already sensitive—microclimate, humidity, drainage, material decay, wind exposure and visitor pressure—and translates those sensitivities into actions, indicators and responsibilities.

The main implementation priority is to convert knowledge gaps into measured baselines: microclimate inside the Sanctuary, runoff and drainage in the buffer zone, local weather monitoring, energy consumption of the pilot lighting area and visitor-flow data. These monitoring actions are essential because several baseline values are intentionally marked as absent, non-tracked or to be measured.

The pilot action is strategically well placed because it is visible, no-regret, replicable and directly manageable by the Municipality. The scenarios set out in Part VI describe the range of results its implementation can deliver, from about 2.7 to 11.3 MWh/year of energy saving and from 0.76 to 3.17 tCO_2/year of avoided emissions depending on the perimeter and the dimming regime, alongside benefits in light-pollution control, evening comfort, safety perception and perceived quality of the heritage setting. These values are consolidated through the light-point census and the executive design, which also fix the final perimeter and the heritage-compatibility pathway agreed with the Soprintendenza.

Overall, the CAP provides a credible transition from climate-risk awareness to implementable action: a medium-term roadmap for 2030, a monitoring architecture for evidence-based review in 2028 and 2031, and a governance mechanism capable of keeping the UNESCO site, the Municipality and the local community aligned after the CAMPUS project ends.

