



IMPETUS

Turning climate commitments into action

Deliverable Report

Enabling rapid and far-reaching change for climate change adaptation by Governance Models, Awareness and Behavioural Change

30.11.2025

D4.5

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Abbreviations

Abbreviation / Acronyms	Description
AI	Artificial Intelligence
BEF	Baltijas Vides Forums
BWB	Berlin Water Utility
BWM	Best Worst Method
CAPEX	Capital Expenditure
CC	Climate Change
CCA	Climate Change Adaptation
CCS	Carbon Capture Storage
CEA	Controlled Environmental Agriculture
CRA	Climate Risk Assessment
DS	Demo Site
DSS	Decision Support System
DST	Decision Support Tool
DTh	Decision Theatre
EC	European Commission



EU	European Union
EURAC	Eurac Research
EUT	Eurecat
GCF	Global Climate Forum
GHG	Greenhouse Gas
GIS	Geographical Information System
IC	Impact Chain
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
JDC	Jelgavas Didgitalais Centrs
KGE	Kling-Gupta Efficiency
KPI	Key Performance Indicator
KTM	Key Type of Measures
KWB	Kompetenzzentrum Wasser Berlin
MAICH	Mediterranean Agronomic Institute of Chania
MCDM	Multi-Criteria Decision-Making
MOOC	Massive Open Online Courses
MSP	Marina Spatial Planning
NBS	Nature-Based solutions
ND	The Netherlands
NTUA	National Technical University of Athens
NWRM	Natural Water Retention Measures
PoR	Port of Rotterdam
PV	Photovoltaic
RCP	Representative Concentration Pathway
RKB	Resilience Knowledge Booster
SenMVKU	Berlin Senate for the Environment
SH	Stakeholders
TFFK	Troms og Finnmark fylkeskommune
ToC	Theory of Change
UiT	Arctic University of Norway
URV	Rovira i Virgili University
WEFE	Water-Energy-Food-Ecosystem
WEI	Water & Energy Intelligence BV
WP	Work Package
ZPR	Zemgale Planning Region



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Executive Summary

This document describes the implementation of adaptation solutions based on **Governance Models, Awareness and Behavioural Change in the demo sites (Bundle 4)**, undertaken or completed in period M6-M50 of the IMPETUS project (01/03/2022 to 31/12/2025), and in particular, those carried out under WP4 Tasks 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, and 4.25.

This deliverable presents the results of a suite of adaptation solutions implemented across the IMPETUS DSs, each addressing climate challenges through participatory governance, data-driven tools, and context-specific approaches. The solutions span **multiple sectors** (water management, agriculture, tourism, cultural heritage, marine planning, risk governance, industrial decarbonisation, and greenhouse agriculture) illustrating how climate adaptation can be **integrated into diverse policy and practice arenas**.

Across all tasks, a central finding is that climate information becomes actionable only when coupled with **inclusive, transparent engagement processes**. Solutions such as the Berlin Water Model (Task 4.18), the altitude-shift viticulture study in Trentino (Task 4.17), and the dynamic planning tools for marine and tourism sectors (Tasks 4.19 and 4.22) show that scientific modelling gains real value when stakeholders can interact with it, explore scenarios, and **use results to inform local decisions**. This approach consistently increases trust in scientific outputs and enhances the relevance and uptake of adaptation measures.

A second major insight is the importance of **multi-level governance and co-creation**. Workshops, impact-chain exercises (Task 4.23), digital twins (Task 4.25), and story maps (Task 4.19) provided shared spaces where public authorities, practitioners, businesses, researchers, and citizens aligned their priorities and identified feasible adaptation pathways. This collaborative effort proved particularly effective in **complex contexts** (such as cultural heritage protection, climate risk governance, and water-oriented forest transformation) where institutional fragmentation or competing interests can hinder progress. Stakeholder involvement from the early stages emerges as a key success factor across the entire suite of solutions.

The tasks also highlight that **behavioural and cultural dimensions** are essential components of adaptation, shaping vulnerability, risk perception, and acceptance of new measures. Work in the tourism and cultural heritage sectors (Tasks 4.22 and 4.21) demonstrated that perceptions, traditions, and local identity influence how communities engage with climate risks. Similarly, agricultural and industrial solutions (Tasks 4.20 and 4.25) underscored how **awareness, incentives, and clear communication** can support behavioural change toward more sustainable practices.

Finally, the deliverable identifies **strong potential for transferability and scalability**. Many methods tested (real-time scenario simulations, participatory governance formats, climate dashboards, impact-chain libraries, monitoring tools, and integrated assessment frameworks) are flexible and can be adapted for other regions or sectors. Their success relies on three elements repeatedly observed across the tasks: **user-friendly design, integration with existing planning instruments, and sustained engagement with local actors**.

Overall, the solutions presented demonstrate that adaptation is most effective when scientific evidence, institutional coordination, and societal engagement work in synergy. Together, they provide practical examples of how European regions can develop **robust, inclusive, and forward-looking strategies for building climate resilience**.

1 Introduction and background

IMPETUS builds on the demonstration of innovative technical, nature-based, governance, financing and public engagement solutions deployed in seven demo-sites (WP4). The IMPETUS demo-sites (DS), as depicted in Figure 1, are designed to cover multiple biogeographical areas, vulnerabilities to climate change, weather-related hazards, as well as economic and socio-demographic conditions.



Figure 1: Overview of IMPETUS demo sites.

A short description of the targeted issues addressed in the regions:

DS#1 Continental: Berlin-Brandenburg region, GER

The Berlin-Brandenburg region consists of the capital and the surrounding municipalities of Brandenburg. The area faces increasing water stress and relies on riverbank filtration, groundwater, and groundwater recharge as sources of drinking water. However, some surface waters used for bank filtration are impacted by treated wastewater discharged upstream, creating a partially closed water cycle. With the anticipated effects of climate change, drinking water quality in the region is at risk. Additionally, a growing population and competing water demands make adaptive solutions essential.

DS#2 Coastal: Coast of Catalonia, ESP

The Catalan coast stretches 600 km along the Mediterranean Sea. The hotspot status of the DS arises from a combination of natural and social factors, driven by a diverse range of economic activities and interests. As a climate-vulnerable area, protecting the environment and conserving natural resources are crucial today and will become even more critical in the future, given the projected impacts, trends, and challenges.



DS#3 Mediterranean: Region of Attica, GR

The Attica Region, which includes the Athens metropolitan area, covers 3,808 km² and is home to approximately 3.74 million residents (as of 2019). As a typical Mediterranean region, it faces increasing impacts from climate change and other global challenges. Overpopulation and competing economic land uses place significant pressure on the environment. Rising temperatures have led to more extreme heat, higher drought risk, and reduced rainfall, affecting both people and ecosystems. Water demand for agriculture and environmental needs competes with the growing tourism and recreation sectors. Over-extraction of groundwater has caused seawater intrusion, reducing crop yields and threatening economic sustainability. Additionally, rising temperatures have driven up energy demand, intensified flash floods, worsened air quality, and increased the risk of forest fires.

DS#4 Atlantic: Province of Zeeland and Rijnmond, NL

Zeeland is a coastal province made up of a series of islands and peninsulas. Both Zeeland and Rijnmond lie at or below sea level, making them highly vulnerable to flooding and rising sea levels. Climate change has led to increasing air temperatures, causing heat stress, particularly in large, exposed landscapes, and posing risks to public health. This challenge is especially concerning given the region's aging population and an environment that is not easily adaptable. Additionally, Rijnmond holds significant economic importance for the Netherlands, as the city of Rotterdam and Europe's largest port are located here. The region's energy consumption is substantial, accounting for 15% of the country's total.

DS#5 Arctic: Troms & Finnmark County, NO

Climate change is already having a significant impact on the Arctic region of northern Norway, particularly in Troms County. Over the past century, Norway's average surface air temperature has increased by at least one degree. Alongside this warming trend, the region is expected to experience more frequent and intense heavy rainfall, floods, landslides, and avalanches. Additionally, sea levels are projected to rise by 10–60 cm by the end of the 21st century, based on the Representative Concentration Pathway (RCP) 8.5 emissions scenario.

DS#6 Boreal: Zemgale Region, LV

Located in central Latvia, the landscape of Zemgale Region is characterized by a flat terrain and dense river network. Therefore, the region is highly vulnerable to flooding, particularly from snowmelt and heavy precipitation. During flood events, the rapid and significant rise in water levels poses substantial risks to communities, settlements, and infrastructure.

DS#7 Mountainous: Valle dei Laghi, IT

The Valle dei Laghi, in the Autonomous Province of Trento, is part of the climate-sensitive Alps. Water resource conflicts among irrigation, hydropower, ecosystem needs, and drinking water are intensifying. In summer, competition between irrigation and hydropower production is already evident. The altitudinal shift of areas suitable for vineyard cultivation requires optimized irrigation and new concessions, further fueling land-use conflicts between agriculture, woodlands, and pastures.

The solutions implemented in the DS are thematically organised in four bundles, each focusing on different aspects of climate adaptation strategies:

- **Bundle 1:** Nature-based Solutions;
- **Bundle 2:** Innovative Technologies;
- **Bundle 3:** Financing & Insurance;
- **Bundle 4:** Governance models, Awareness and Behavioural change.

This document presents the results of **Bundle 4**. Bundle 4 of Work Package 4 (WP4) focuses on the demonstration and deployment of **non-technical, governance-driven, and behavioural change solutions** that support climate adaptation across the seven IMPETUS demonstration sites. While WP4 showcases a wide array of innovative technical, nature-based, financial, and public engagement strategies, Bundle 4 zooms in on the **human and institutional dimensions** of climate resilience. These tasks explore how **governance models, cultural values, participatory planning, and awareness-raising initiatives** can collectively foster more effective and inclusive adaptation responses (see Table 1). Together, these tasks highlight how inclusive governance frameworks, public engagement, and behavioural transformation are critical levers for successful climate adaptation.



The Deliverable 4.5 documents the implementation, results, and lessons learned from **Bundle 4 activities**, with the goal of showcasing how **governance innovation and behavioural change** can strengthen resilience in diverse territorial and socio-economic contexts. The objectives are to:

- Demonstrate how participatory governance models improve decision-making under uncertainty.
- Test awareness-raising strategies and community-based planning tools tailored to local contexts.
- Support behavioural shifts in sectors such as tourism, agriculture, energy, and industry.
- Offer practical, transferable models and digital tools that can guide climate adaptation efforts across Europe.

The results from Bundle 4 contribute to building **robust, place-based adaptation solutions** rooted in shared knowledge, institutional capacity, and cultural values. These solutions are expected to:

- Enhance multi-level governance and stakeholder collaboration.
- Foster cross-sector synergies and reduce conflicts over resource use.
- Promote socially inclusive and economically feasible adaptation strategies.
- Feed into the overall IMPETUS framework for scalable, co-created resilience solutions.

By linking behavioural, cultural, and governance innovations, this bundle reinforces the importance of **people-centred adaptation approaches** that complement technical and financial innovations demonstrated in other bundles of WP4.



Table 1: Overview of WP4 tasks in Bundle 4.

<i>Solution</i>	<i>Task No.</i>	<i>Lead beneficiary</i>	<i>Demo site</i>	<i>Task description</i>
Evaluation of the effects of the altitudinal shift of crops on vineyards	4.17	EURAC	7 (Italy)	The Task investigates how shifting vineyards to higher altitudes can serve as an adaptation strategy to climate change, with a focus on Chardonnay for sparkling wine in Trentino. Two vineyards at 230 m and 700 m a.s.l. are compared using detailed climate, soil, phenological, and productivity data. Results show that higher-elevation sites develop later, retain higher acidity, and preserve aromatic freshness, while lower sites ripen earlier and show higher yields. Long-term data monitoring (1999-2025) also reveals faster warming at higher altitudes, potentially narrowing traditional differences between sites. The task combines field measurements, digital monitoring tools and stakeholder workshops to assess impacts and co-design adaptation measures, ultimately supporting regional strategies for climate-resilient viticulture.
Stakeholder workshops	4.18	KWB	1 (Germany)	This task focuses on facilitating Decision Theatres in the Berlin-Brandenburg region to integrate scientific water models with policymaking and stakeholder dialogue. Workshops are organised to demonstrate the Berlin Water Model and to explore climate-resilient water management strategies. The task aims to bridge the gap between scientific modelling and political and practical decision-making, strengthening stakeholder collaboration and elevating the visibility of the project within regional and EU climate resilience agendas.
Co-designed Marine Spatial Planning Framework	4.19	TFFK	5 (Norway)	This task involves the development and Co-design of a Marine Spatial Planning framework covering the arctic coastline of Troms and Finnmark. The solution is a highly functional ArcGIS environment integrated with marine spatial plans, marine infrastructure, climate predictions and marine ecological data. The overarching goal is to improve the planning and preparedness for climate change and mitigate risk to important industries such as fishery and aquaculture.
Multi-purpose Controlled Environmental Agriculture	4.20	MAICH	3 (Greece)	This task demonstrates the potential of smart technologies in sustainable greenhouse farming. It features a decision support system that uses sensors, actuators, and machine learning to monitor environmental conditions and recommend equipment adjustments, optimizing microclimates for crops. Tested at the Attica Green hydroponic greenhouse near Athens, the system operates in a challenging peri-urban environment. The 0.2 ha facility includes



				energy-saving features such as natural ventilation, thermal curtains, and fan-and-pad cooling systems. These innovations improve resource efficiency, reduce environmental impact, and support precision agriculture. The project highlights the viability of controlled environment agriculture for resilient, eco-friendly food production.
Cultural Heritage as a solution to enable climate resilience	4.21	EURAC	7 (Italy)	The task focuses on both intangible and tangible heritage. It aims to utilize the local knowledge that communities have developed over time to manage climate risks, while also examining how culture, values, and beliefs affect risk perception and adoption of adaptation measures. Key cultural practices and traditions are identified and evaluated to suggest climate adaptation strategies, particularly in the agricultural sector, including winemaking. Another aspect of the project involves examining historical buildings. By analysing the building stock of a valley, two representative buildings from two villages were chosen. Their historical changes were studied, and dynamic simulations were performed on both their original and current states (post-renovation) for seven different climates (past, near, and far future for three carbon pathway scenarios). The findings informs renovation strategies and technical solutions to cope with climate change, eventually leading to a comprehensive scenario combining all strategies and solutions.
Behavioural change for climate resilient tourism	4.22	URV	2 (Spain)	This task promotes climate-resilient tourism by fostering behavioural change through stakeholder co-creation. It focuses on three key areas: developing climate potential indicators to align tourism with seasonal climate conditions; assessing perceptions of water and energy use in tourism to encourage sustainable practices; and increasing awareness of beach-dune systems' role in coastal resilience. Participatory workshops support shared understanding, tool development, and identification of barriers to sustainable tourism. Through this integrated approach, stakeholders co-develop metrics, strategies, and visual tools that enhance adaptive capacity, aligning tourism activities with climate realities and promoting long-term resilience across destinations.
Impacts Chains application	4.23	EURAC	7 (Italy)	The Impact Chain (IC) method is a widely used framework for climate risk assessment and adaptation planning. It conceptualizes risk as the interaction between hazard, exposure, and vulnerability, in line with the IPCC's AR5 framework. The method supports prioritizing adaptation actions by targeting key vulnerability and exposure drivers. The Rapid Risk Management Appraisal (RRMA), a complementary tool, assesses risk management capacities through expert-based, participatory approaches. Applied in the



				Alps, RRMA enhances emergency planning links. Within IMPETUS, ICs focuses on agriculture and built environments, be standardized using KUMU, and expanded into a replicable library and guidelines.
Climate Change Adaptation Plan governing climate risk management	4.24	BEF	6 (Latvia)	This task focuses on the Zemgale Regional Climate Change Adaptation Plan (CCA Plan) that was developed to enhance regional resilience by applying a tailored participatory planning approach that involves stakeholders from public, private, and civic sectors. The plan establishes a systemic framework for climate adaptation, addressing cross-sectoral dimensions such as agriculture, forestry, water, energy, and health, while ensuring that the needs of municipalities and sectors are reflected through jointly selected and accepted adaptation measures.
Decision Support Tool for Industrial Decarbonisation	4.25	WEI	4 (Nederland)	This task focuses on the development of a Decision Support Tool to aid decision makers to take smart and well-informed decisions on decarbonisation strategies in the Rotterdam port industrial cluster (Atlantic DS). The decarbonisation considers several phases including the recovery of waste heat and the electrification of process systems. The tool maps waste heat sources, recovered heat symbiosis and energy usage patterns, thus supporting waste heat integration. It also has options to add layers of different utility provisions, its requirements and usage patterns of different industrial segment. This enables industrial symbiosis and potentially support circular economy. A participatory approach is adopted to gather the required data needed, by identifying the current energy and raw materials (including water) consumption, as well as emissions generated by the companies located in the cluster.



2 Innovative Solutions Implementation

The innovative solutions in **Bundle 4** are applied and implemented in all the **7 demonstration sites** within the project.

2.1 Evaluation of the effects of the altitudinal shift of crops on vineyards (Task 4.17)

Around 2018, climatologist Georg Kaser released a report that sounded the alarm on some of the world's most important wine regions, including those in Italy: these areas are projected to see a reduction in their cultivable land by 25% to 73% by 2050, and winemakers will need to search for new lands, often at higher altitudes. Since 2000, there have been 24 key studies on the impact of altitude on grapes and wine (6 white grape, 21 red grape). High-altitude cultivation promotes higher acidity, greater levels of aromatic compounds in the grapes, as well as higher total phenols, anthocyanins, flavonols, total monoglucoside anthocyanidins, and condensed tannins in grape skins, along with excellent sensory characteristics in the wine, such as elegance, specific vegetal notes, and floral aromas. Other studies, however, have highlighted better performance in medium- and low-altitude vineyards.

Vineyard location (altitude, latitude, slope, and orientation), planting material (varieties, clones, and rootstocks), training system, soil type, and solar radiation are all factors that influence grape and wine quality; it is very difficult to determine exactly how each individual variable affects it, which is why some articles report contradictory results in the literature (Mansour et al., 2022).

In the project demonstration site of Valle dei Laghi, efforts are already underway to update the regulations governing certain types of wine production, such as sparkling wines. At the same time, ongoing discussions among winemakers, local authorities, and residents are focusing on the relationship between viticulture and mountain landscapes. This dialogue was particularly emphasized during the meeting held on October 11, 2024, in Brentonico (TN), titled "The Trentino Monte Baldo: a dialogue between viticulture and mountain Landscapes".

Concerning strategies for addressing climate change, adaptation – alongside long-term mitigation measures – provides a more immediate response, enabling viticultural and winemaking practices to adjust to changing environmental conditions.

The objective of this task is to deepen our understanding of how high-altitude viticulture influences wine production, with particular attention to Chardonnay grapes intended for sparkling wine.

An analysis of recently published data on the distribution of the main grape varieties in Trentino from 2011 to 2021 indicates that, for some cultivars, there has been an upward shift in the average elevation of their growing areas. This trend reflects an adaptive response to rising temperatures, which particularly affect varieties intended for sparkling wine production or those that undergo a marked degradation of organic acids (mainly malic acid) as heat increases.

Increasing vineyard elevation is therefore emerging as a key adaptation strategy to climate change, as it allows producers to preserve the compositional characteristics of grapes—especially those destined for sparkling wine base production, which represents a significant and growing share of Trentino's wine sector. At the same time, red grape varieties, being later-ripening and requiring higher thermal inputs, could be better valorised in the warmer valley-floor areas.

Evaluating the effects of this altitudinal shift involves a multifaceted approach that considers environmental, physiological, and product-related factors.

Our work has been organized around two interconnected objectives, both designed to study the effects of increased altitude on viticulture:

1. The first objective of this task was to investigate how altitude influences the phenology and vegetative–productive characteristics of vineyards intended to produce either still wine or the base for sparkling wine (Chardonnay cultivar), while also assessing its impact on the characteristics of the final product.
2. The second objective was to combine advanced edaphic–environmental monitoring systems with the characterization of vine productivity and the chemical properties of both intermediate and final products of the winemaking process. Continuous monitoring systems have been implemented in two vineyards located at different elevations – 230 m and 700 m a.s.l. – to characterize the pedological and climatic conditions of the canopy, which are crucial to achieving the project's objectives.

These activities are detailed in the project amendment that officially allowed the Edmund Mach Foundation to join the initiative, received on July 10, 2024.

2.1.1 Results

The study was carried out in two commercial vineyards, called 'Bottom' – located in S. Michele all'Adige (lat: 46.192226N lon: 11.137505E, 230 m a.s.l.) – and 'Top' – located in the same municipality, in the



Faedo hamlet (lat: 46.195469N, lon: 11.170754E, 700 m a.s.l.) – both managed by Fondazione E. Mach and planted to *Vitis vinifera* L. cv. Chardonnay and Vertical Shoot Position (VSP) trained, with Guyot pruning system (Figure 22). For the experiment, two Chardonnay clones were selected: ENTAV-INRA 96 (characterized by medium vigor, suitable for sparkling wines) and ENTAV-INRA 76 (producing fine, aromatic, well-balanced, and typical wines).

The following surveys and measurements were conducted:

- In 2024, the first year of the project, soil analyses and leaf sampling were carried out for mineral element determination, in order to assess potential differences in the nutritional status between the two vineyards.
- During the 2024-2025 period, for both clones and experimental sites, SPAD optical index measurements (SPAD-502, Minolta, USA) were taken on 30 vines at the BBCH 73–75 phenological stage, to monitor leaf colour and chlorophyll content. At the same time, NDVI optical index measurements were performed across the entire vineyard surface of both clones using a GreenSeeker® Handheld sensor (Trimble), resulting in a total of 3152 point measurements over the two-year period.
- In both growing seasons, agronomic data were collected on 30 vines per clone, describing the vegetative and productive development of the vineyards. The recorded parameters included actual fertility, number of shoots, number of clusters, yield weight, pruning wood weight, and the Ravaz index.
- Starting from veraison, ripening curves were established by means of measurements taken with a portable optical refractometer, in order to monitor sugar accumulation and determine the progression toward technological ripeness. To define the harvest date, must analyses were performed, assessing not only sugar content but also total acidity and pH. Once technological maturity was reached (sugar content ranging between 17.5° and 19° Brix), three harvest replicates were carried out for each clone, yielding a total of 12 grape samples (approximately 30 kg each) for experimental vinification.
- The musts were subjected to characterization analysis of the varietal aromatic compounds, considering both the free and bound fractions. At the end of alcoholic fermentation, the resulting wines were subjected to chemical analyses.
- Microclimatic Data and Bioclimatic Indices. The main microclimatic parameters—air temperature, relative humidity, solar radiation, and precipitation—were recorded hourly by two meteorological stations, managed by the Agrometeorology and Irrigation Unit of FEM-CTT, located near the vineyards. These data were used to calculate several bioclimatic indices relevant for assessing viticultural suitability. One of the key indices considered was the Winkler Index, which represents the sum of air temperatures above 10 °C during the growing season (Growing Degree Days, GDD; April 1–October 31). This index provides an estimate of the thermal potential for grapevine cultivation. Thermal availability, strongly influenced by altitude, plays a crucial role in defining vineyard climatic conditions. Accordingly, the Faedo vineyard (Winkler Index: 1320 GDD, Region II) is situated in a cooler area compared to the San Michele all'Adige vineyard (Winkler Index: 1770 GDD, Region III). The mean growing season temperature (GST; Jones et al., 2005) during 2024 was 15.22 °C (intermediate) at Faedo and 15.92 °C (warm) at San Michele all'Adige. The year 2024 was particularly rainy, with total precipitation of 1700 mm and 1534 mm, respectively.
- Climatic Differences Between the Two Study Sites (1999–2025). Based on data from 1999 to 2025 (Table 9), the bottom site (San Michele all'Adige) exhibits a generally warmer climate and a longer growing season, with higher accumulated growing degree days (1770 vs. 1320) and a higher mean growing season temperature (18.3 °C compared to 15.9 °C at the top site, Faedo). Spring frosts occur more frequently at the top site (0.96 vs. 0.56 per year), indicating greater frost risk. Conversely, the bottom site experiences more hot days (4.04 vs. 0.33 per year), suggesting a higher likelihood of heat stress. Heavy rainfall events are slightly more common at the top site (6.63 vs. 5.41 per year), while the longest dry spells are similar between the two (approximately 15–16 days), indicating comparable drought risk.
- Between 1999 and 2025, both vineyard sites experienced an increase in Mean Growing Season Temperature (GST), confirming a regional warming trend (Figure 25). However, the higher-elevation site at Faedo (700 m) shows a much faster rate of warming than the lower site at San Michele all'Adige (230 m). Faedo (Top, 700 m): GST increased by roughly +0.95 °C per decade, indicating a strong warming trend at higher elevation. San Michele (Bottom, 230 m): GST increased by only +0.18 °C per decade, suggesting slower warming in the valley bottom. This pattern demonstrates elevation-dependent warming, where mountain locations are heating faster than nearby lowlands. The narrowing temperature difference between the sites suggests that high-altitude vineyards are catching up thermally, potentially altering local viticultural suitability.



In terms of soil characteristics, previous FEM soil analyses, corroborated by those conducted within the framework of this study, confirmed the presence of two soil types that are agronomically equivalent. The only notable difference was observed in the 'Top' vineyard soil, which showed slightly higher total phosphorus and potassium contents (Giandon and Bortolami, 2007). The nutritional status of the vines was further evaluated through leaf analyses performed at veraison (BBCH 83–85) during the first year, with results falling within standard reference ranges for both sites (Table 5).

Chardonnay vineyards at lower elevation (230 m a.s.l.) reach phenological stages earlier, including bud break, flowering, and harvest, due to higher thermal availability, resulting in faster sugar accumulation and riper grapes. In contrast, higher-elevation vines (700 m a.s.l.) develop more slowly, extending the growing season and producing grapes with higher acidity, lower pH, and enhanced aromatic freshness. These altitude-driven differences in phenology directly influence grape composition and are key for producing distinct wine styles, with cooler sites particularly suited for premium sparkling wines.

Earlier development at lower elevation: The red and orange points (San Michele, 230 m) consistently reach higher BBCH codes before the green points (Faedo, 700 m), confirming that lower-elevation vines progress faster through phenological stages.

Clone differences: Both Chardonnay clones (cl. 96 and cl. 76) show similar trends, with clone 96 slightly ahead in early stages, but elevation has a stronger influence than clone.

Delayed phenology at higher elevation: Faedo vines (green points) reach comparable BBCH stages roughly 2–3 weeks later, indicating a slower development and extended growing season at 700 m.

Implications: This supports the earlier textual findings that higher-altitude vineyards maintain higher acidity and aromatic freshness due to slower ripening, while lower-altitude sites mature earlier, favouring fuller-bodied still wines.

Regarding fertility, expressed as the number of clusters per shoot, the analysis of variance showed that both year and vineyard had significant effects, with the magnitude of the year effect being clearly greater than that of the site effect (Table 6). The 2024 season was characterized by a markedly lower bud fertility compared to 2025 for both vineyards, although the higher-elevation vineyard also exhibited significantly lower fertility than the one located at lower altitude (Figure 23).

This difference can be readily attributed to the meteorological conditions of spring 2024, during which a late frost occurred at the end of April, causing visible damage, scorching, and desiccation on the newly formed shoots (Figure 24), and presumably affecting bud fertility in that year.

As regards the SPAD and NDVI optical indices, these therefore show a concordance, indicating that the development of the vegetative biomass and the coloration of the canopy varied according to seasonal conditions and clonal differences, but not according to the vineyard site (Table 6).

The effect of the year on quantitative production data was significant, both on the number of bunches and on the yield per vine (Table 7 and Figure 24). Conversely, average bunch weight did not show significant differences between years; however, the effect of the 2024 frost was evident, as it reduced all yield-related parameters in the highest vineyard. The vineyard effect was consistently statistically significant, with the 'Bottom' vineyard showing better performance, except for bunch number (not significant in 2024) and average bunch weight (not significant in 2025).

In 2024, the harvest dates were 21 August for the 'Bottom' vineyard and 11 September for the 'Top' vineyard, which were very similar to those recorded in 2025 (21 August for the 'Bottom' vineyard and 12 September for the 'Top' vineyard). From a quantitative perspective, in 2024, a year characterized by generally lower productivity, the high-altitude vineyard produced 57.3 q/ha, compared with 95.6 q/ha in the lower site. In 2025, in the absence of factors affecting bud fertility, yields reached 140 q/ha in the Bottom vineyard and 100 q/ha in the Top site. This corresponds to a yield loss of 41% in 2024 and 29% in 2025.

The main sources of variability affecting the analytical parameters of the musts were the vintage and the vineyard, while the clone factor was significant only with respect to the yeast assimilable nitrogen (YAN) content. In particular, clone 76 showed an average value of 119 mg/L, compared to 72 mg/L for clone 96. Since no interaction effects between the factors vintage and vineyard were detected following the factorial analysis, the data were analysed independently (Table 8).

About the sugar content of the must, since the harvest date was determined based on reaching a target range of soluble solids – between 17.5° and 19° Brix – it should be considered that the year-to-year variation for this parameter is, to some extent, biased by this selection criterion.

The comparison between vineyards shows that the 20-day difference in harvest date does not eliminate differences in sugar accumulation (18.2° vs. 19.5° Brix), but results in a markedly higher acidity in the high-altitude vineyard (10.5 vs. 8.7 g/L), while maintaining a similar pH from an enological standpoint. The higher acidity is due to the contribution of both major grape acids: not only does tartaric acid, the more structurally stable component, remain at higher levels, but malic acid, which is more sensitive to environmental factors, also maintains a higher concentration.

It is also noteworthy that the concentration of yeast-assimilable nitrogen (YAN) is higher in the high-altitude vineyard (113 mg/L) compared to the lower site (78 mg/L).

Additional vegetative and productive parameters (pruning wood weight, Ravaz index) and data from the 2025 wine analyses (chemical and aromatic) were not available at the time of preparation of this report, but will be incorporated in future publications.

Two workshops were organised in 2024 and 2025 to inform the local stakeholders about the progress in the activities and discuss with them potential new adaptation measures for the sector. The focus was on agronomic approaches, further opportunities from digitalisation in agriculture (with particular attention to water management) and potential dynamics at the landscape level caused by vineyards (re)settlement. These events were organised with a participatory approach, and attendees were involved in a guided discussion centred on adopting a canvas which reflects the key elements of the Impact Chain approach (as for Task 4.23). The evidence arising from one of these workshops is shown in a canvas as in Figure 27. Results of these workshops will be also included in the preparatory materials, related to the agricultural sector, for the local Strategy of Adaptation to Climate Change.

2.1.2 Impact

The integration of climatic, phenological, and agronomic data allows a comprehensive evaluation of how elevation and warming trends jointly shape vineyard performance and future adaptation potential.

Warming Trends in Vineyard Climates:

- The analysis of long-term climate data (1999–2025) successfully quantified warming trends in key agroclimatic indicators (GST and GDD) at two vineyard sites differing in elevation.
- Results clearly demonstrate a significant temperature increase over the past 25 years, with higher warming rates at the top site (Faedo, +0.95 °C per decade) compared to the bottom site (San Michele all'Adige, +0.18 °C per decade). This altitude-dependent warming indicates that mountain viticulture areas are becoming thermally more similar to lower, traditionally warmer zones, potentially altering phenology, ripening dynamics, and varietal suitability.
- The elevation gradient continues to shape vineyard performance, but the narrowing temperature gap points to converging climatic conditions that could reduce the phenological delay traditionally observed at higher elevations. Observations from 2024–2025 confirm that the lower-elevation vineyard ('Bottom', 230 m a.s.l.) reached key phenological stages 2–3 weeks earlier than the higher site ('Top', 700 m a.s.l.), leading to earlier harvests and faster sugar accumulation. Conversely, the high-elevation site maintained higher acidity, lower pH, and greater aromatic freshness, highlighting its continued suitability for sparkling wine production.
- These findings align with the identified warming trends: as the upper site warms faster, its enological profile could progressively shift toward that of lower sites, potentially narrowing the window for sparkling base wine production unless adaptive strategies (e.g., varietal choice, canopy management, irrigation timing) are adopted.
- In addition, the 2024 late frost event had a measurable impact on fertility and yield, particularly at the higher site, reducing cluster number and yield per vine by over 40%.
- Despite similar soil fertility and nutrient status, altitude-related climatic differences were the dominant source of variability in productivity. Clone effects were generally secondary to environmental ones, although clone 76 exhibited higher yeast-assimilable nitrogen (YAN) levels, suggesting potential for site-specific clonal adaptation to varying thermal and nutritional conditions.
- The project thus meets its objective of detecting, quantifying, and interpreting local climate change signals using high-resolution meteorological, agronomic, and phenological data, while also connecting these trends to direct productivity and quality outcomes at the vineyard scale.

Short-term Impacts (operational level):

- The study provides immediate awareness of local warming and its agronomic consequences, supporting adaptive vineyard management.
- The documentation of altitude-dependent warming and frost impacts offers critical insights for tactical decision-making, such as frost protection, pruning timing, and yield regulation.
- Data on phenological shifts, acidity retention, and YAN variation establish a baseline for monitoring quality-related parameters under changing climatic conditions.
- Results from participatory workshops in 2024–2025 increased stakeholder engagement and awareness, stimulating discussion on agronomic measures, digital tools, water management, and land-use adaptation strategies, framed within the Impact Chain approach.



- The integration of NDVI and SPAD data demonstrates the usefulness of digital monitoring tools for real-time canopy assessment and early detection of seasonal stress differences, even when vineyard site effects are minimal.

Long-term Impacts (strategic level):

- The results provide a foundation for forecasting future varietal suitability under continued warming, particularly in mountainous viticultural areas experiencing accelerated temperature increases.
- By linking climatic trends to vine performance and must composition, the work supports long-term adaptation planning, including clone selection, harvest scheduling, and re-zoning for sparkling versus still wine production.
- Continuous, site-specific monitoring of agroclimatic indices and phenological data strengthens regional resilience and adaptive capacity within viticulture.
- The study emphasizes the strategic value of maintaining high-elevation vineyards as climate buffers, while also highlighting the need to anticipate potential thermal convergence with valley sites.
- Engagement with local stakeholders contributes to a co-creation process for adaptation measures, ensuring that research outcomes directly inform regional policy and viticultural practice.

2.1.3 Lessons Learned

Key Takeaways

- Long-term, high-resolution climate monitoring proved essential for detecting subtle but significant warming trends at local vineyard scale, confirming elevation-dependent warming rates (+0.95 °C per decade at Faedo vs. +0.18 °C per decade at San Michele).
- Altitude strongly modulates vine phenology and grape composition: lower sites advanced through growth stages 2–3 weeks earlier, while higher sites retained higher acidity and aromatic freshness, reaffirming their suitability for sparkling base wines.
- Extreme events (late spring frost) can override gradual climate trends, with clear impacts on fertility and yield (up to –40 %), highlighting the need for combined climate–agronomic monitoring.
- Digital canopy indicators (SPAD, NDVI) provided consistent, real-time assessments of vine vigor, demonstrating the potential of precision viticulture tools for adaptive management.
- Clone-specific differences, such as higher yeast-assimilable nitrogen (YAN) in clone 76, emphasize the importance of genotype–environment interactions when defining adaptive strategies.
- Participatory engagement with local stakeholders, through workshops and Impact Chain exercises, enhanced knowledge exchange, strengthened adaptation awareness, and fostered co-design of management options under changing climatic conditions.

Challenges Encountered

- Incomplete or inconsistent historical datasets required extensive validation, homogenization, and statistical gap-filling to ensure the robustness of long-term trend analysis.
- Frost damage in 2024 complicated comparisons of fertility and yield across years, necessitating careful interpretation of interannual variability.
- Variability in sensor calibration and sampling frequency (e.g., between SPAD, NDVI, and weather stations) demanded cross-validation to maintain data comparability.
- Limited availability of complete agronomic datasets (e.g., pruning wood weight, Ravaz index, and 2025 wine chemistry) temporarily constrained full quantitative assessment of vine balance and wine outcomes.
- Stakeholder heterogeneity—ranging from small producers to institutional vineyards—posed challenges for aligning perceptions of climate risk and adaptation priorities. As well as their continuous and representative participation, this is an element which should be supported and maintained to activate a shared adaptation pathway.

Future Recommendations

- Maintain and expand long-term meteorological and phenological monitoring, especially at high elevations where warming rates are fastest.
- Integrate digital vineyard tools (NDVI, SPAD, remote sensing) into routine management to detect stress, optimize irrigation, and anticipate phenological shifts.
- Incorporate frost risk and heat stress indices into predictive models to improve early warning systems and guide adaptive practices.



- Link bioclimatic indicators with grape composition metrics (sugar–acid balance, YAN) to refine models of varietal suitability under future scenarios.
- Standardize data collection protocols across sites and projects to enhance comparability and scalability of findings.
- Continue participatory workshops to co-develop and test adaptation measures, ensuring strong feedback loops between science and practice. Setting the elements which can support the establishment of living-lab approaches.

Barriers to Transferability

- Local topography and microclimatic variability limit direct extrapolation to other regions; results must be interpreted within site-specific contexts.
- Differences in grape varieties, training systems, and management practices influence responses to climate drivers and may alter impact magnitudes.
- Data-intensive requirements—especially long-term, high-frequency meteorological and phenological records—pose logistical and financial barriers for replication elsewhere.
- Institutional coordination is needed to ensure long-term maintenance of monitoring infrastructure and data accessibility for future climate adaptation research.

2.1.4 Conclusion

The integrated analysis of long-term (1999–2025) climatic, phenological, and agronomic data from two commercial Chardonnay vineyards confirmed a clear warming trend in the region, with higher elevation sites warming more rapidly (+0.95 °C per decade at Faedo, 700 m a.s.l.) than lower valley sites (+0.18 °C per decade at San Michele all’Adige, 230 m a.s.l.). This altitude-dependent warming has already led to measurable shifts in vine phenology, ripening dynamics, and grape composition. Lower sites reached harvest approximately three weeks earlier and accumulated sugars more rapidly, while higher-elevation vineyards retained higher acidity, lower pH, and enhanced aromatic freshness, maintaining their potential for premium sparkling wine production.

Interannual variability—especially the late frost event in 2024—demonstrated that extreme weather events, such as the 2024 frost, significantly affected yield and fertility, confirming that climatic variability—rather than soil or nutrition—is the main driver of vineyard performance.. Clone-specific differences, such as higher YAN levels in clone 76, further highlight the importance of considering genotype–environment interactions in adaptive vineyard strategies.

The study reinforces the value of continuous, high-quality monitoring of agroclimatic and phenological indicators (e.g., GST, GDD, SPAD, NDVI) for evidence-based vineyard management. Such data provide early warning of phenological advances and productivity risks, supporting site-specific adaptation measures such as optimized pruning timing, frost protection, and clone or varietal selection.

From a broader perspective, the results confirm that mountain vineyard regions are warming faster than valley floors, suggesting a progressive convergence of climatic conditions across altitudinal gradients. This trend underscores the need to preserve and adapt high-elevation viticulture, both as a thermal refuge and as a strategic resource for maintaining wine style diversity under climate change.

Future research and policy should focus on expanding long-term monitoring networks, standardizing data collection, and integrating climate projections with vine performance models to refine predictions of varietal suitability and guide resilient viticultural development. The participatory approach adopted in this project—linking scientific results with stakeholder knowledge—proved effective for fostering awareness and co-designing practical adaptation strategies that strengthen the resilience of local wine production systems.

Tables and figures are reported in the Annex.

2.2 Stakeholder workshops (Task 4.18)

Task 4.18, as part of the Berlin-Brandenburg Demo Site, was originally launched with an ambitious scope. The primary objective was to facilitate multiple Decision Theatres (DTh), a methodology integrating model simulations with interactive visualizations to engage academia, practitioners, and policymakers in decision-making processes, fostering collaboration and knowledge exchange. The goal was to produce actionable insights and policy recommendations by leveraging model simulations developed under Task 4.7.1. These models focused on regional integrated water resource management, specifically addressing climate-induced challenges (see D4.3).

In the early stages, Task 4.18 aimed to explore the future of water management practices in the Berlin-Brandenburg region through climate scenarios, with a focus on water quality and quantity. This was



done experimenting with various policy options and use model simulations (developed in parallel) to predict potential outcomes under different scenarios.

However, the execution of the task faced significant delays due to challenges encountered by the original lead partner, GCF. Despite multiple attempts to resolve issues and secure their commitment in close coordination with the project management team, it became apparent that GCF was unable to fulfil the task's requirements. After months of project duration, and following unsuccessful efforts to engage the original partner, KWB took over full responsibility for Task 4.18 in early 2025 to ensure progress and deliver tangible results. KWB recognized from the beginning that the successful completion of this task was critical for the visibility and credibility of the models developed under Task 4.7.1 and for the DS as a whole.

Since assuming responsibility, KWB has worked to complete the task within the remaining timeline. This has involved organizing and preparing three key workshops aimed at demonstrating the Berlin Water Model (see T4.7.1 in D4.3), engaging a broad range of stakeholders, and ensuring the integration of scientific models into practical, policy-relevant scenarios. Despite the challenges posed by the delayed start and the shift in methodology, KWB has successfully advanced the objectives of Task 4.18.

2.2.1 Results

Task 4.18 advanced both the application of the Berlin Water Model developed under Task 4.7.1 and the integration of climate risk mitigation strategies into regional water management practices. The efforts were focused on engaging a broad spectrum of stakeholders, as outlined in the objectives, and facilitating key workshops to translate the scientific results into practical, actionable insights.

Stakeholder Engagement and collaboration

One of the main achievements of the task and the overall DS has been the strong engagement of the Berlin Water Utility (BWB) and the Berlin Senate for the Environment (SenMVKU), who have been involved as project partners from the beginning of the project. It was the first time SenMVKU took over project partner role, developing their own model, instead of being only associated to the project. This early collaboration ensured that the most relevant authorities were included in the planning and application phases. Beyond this core group, the circle of engagement was extended to include a diverse set of stakeholders, including representatives from NGOs, forestry, and research sectors. These efforts were carried out in close coordination with WP1: Stakeholder Engagement. The resulting stakeholder register (see T1.1 of WP1) and build the groundwork of the stakeholder groups to engage throughout the project and invite for the key stakeholder workshops.

Scenario selection based on the Masterplan Wasser

A key element of preparing for the workshops was selecting and prioritizing the scenarios that would be explored with stakeholders. This selection was strongly guided by the *Masterplan Wasser*, a strategic document developed by SenMVKU in 2022 that outlines Berlin's long-term water management goals. To facilitate this process, a series of collaborative meetings were organized with the core stakeholder group. In these meetings, potential inputs were presented and discussed how these could be integrated with existing strategies and data into the model development. One of the outcomes was the development of a function tree to simplify the complex Berlin water system and better visualize its key components. This provided a clearer framework for understanding how different factors, such as water extraction, wastewater treatment, and groundwater recharge, interact within the system.

A critical part of the selection process was the integration of measures from the *Masterplan Wasser*, which had been identified as priorities for Berlin's future water management. To support this, a questionnaire was developed to gather data on these measures, ensuring that the scenarios chosen would be aligned with not only technical feasibility but also policy relevance. Additionally, vital information on water demand projections, technical measures related to water extraction, and the scope of planned infrastructure projects, which helped refine the potential scenarios. Through this collaborative process, KWB ensured that the selected scenarios were not only scientifically sound but also directly tied to the region's strategic planning documents, including the Masterplan Wasser. This approach increased the likelihood that the insights gained through the DTh sessions would be directly applicable to future policy decisions.

Workshop 1: Demonstrating the Berlin Water Model

The first workshop was designed to showcase the Berlin Water Model, developed under Task 4.7.1, and to demonstrate its capabilities in supporting climate risk mitigation strategies related to water management. The workshop agenda was structured to provide a comprehensive overview of the



model's functionality, followed by interactive demonstrations of how it could be applied to various real-world scenarios.

The session began with an introduction to the IMPETUS project objectives, the model's development, giving participants a clear understanding of the context in which it was created and its relevance to Berlin's future water management under climate-induced scenarios. This was followed by an explanation of the model structure, which detailed the data and assumptions that informed the model's calculations. Key datasets, including climate projections, demographic trends, and water system data from the Berlin water authorities, were discussed to ensure transparency about the model's inputs.

A key part of the workshop involved validating the model by comparing its outputs with existing calculations from the Masterplan Wasser, using the HYDRAX/QSim models at specific points in the Berlin water network. This validation exercise, carried out for two distinct scenarios, provided stakeholders with confidence in the model's accuracy and reliability, ensuring it was aligned with current planning documents and strategies.

Following a short break for informal exchange and networking, the workshop moved into the heart of the demonstration: scenarios and live calculations. Participants were shown how the model reacts to various changes in key parameters, such as reduced inflows, shifts in evaporation rates, and changes in the proportion of rainwater versus wastewater entering the system. They also observed how the model responded to changes in pollutant inputs, which directly affect water quality.

The live scenario calculations were a particular highlight of the session. Stakeholders were able to see in real time how different policy measures, including planned large-scale infrastructure projects, could impact water quality and availability. This was a highly valuable aspect of the workshop.

The workshop concluded with a discussion on how the model could be further optimized to meet the specific needs of stakeholders. The dialogue focused on identifying areas where the model could be fine-tuned, and where additional scenarios or parameters might be added to enhance its relevance for future water management decisions. Stakeholders provided valuable feedback on which questions remained unanswered and how the model could be adjusted to better address their specific concerns.

Overall, the workshop was a success, with stakeholders gaining a deeper understanding of the model's potential applications and its capacity to inform decision-making in water management. The interactive and practical nature of the session, especially the ability to simulate and visualize real-world scenarios, played a critical role in fostering collaboration and ensuring that the model's outputs would be directly applicable. After the workshop, multiple stakeholders reached out to organize further applications of the model in the future tailored to their specific needs and questions.

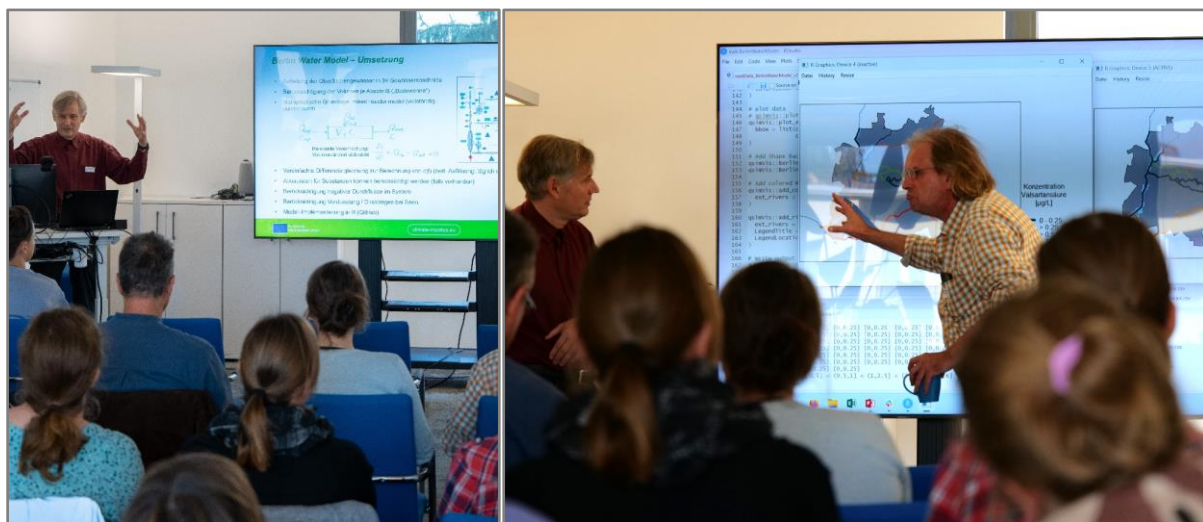


Figure 2: Impressions from the workshop: Left: technical presentation of the visualised function tree to simplify the complex Berlin water system. Right: An engaged stakeholder during the live scenario calculation and visualisation of questions raised by the audience, with implications shown for Berlin's water bodies.

Workshop 2: Political engagement

Workshop 2 is planned as a high-level political breakfast (*Politikdialog*) with environmental spokespeople from all democratic parties in the Berlin Parliament. This event, scheduled after the

submission of this deliverable, builds directly on the success of Workshop 1. The aim is to translate the findings from the first workshop (mainly from practitioners) into the political sphere.

One of the key highlights of this workshop is the broad political engagement it has generated. Initially, we expected policymakers to be more hesitant in attending, especially given the political sensitivity of water issues and their effect on the public when communicated not clearly. However, to our surprise, all environmental spokespeople from the major political parties in the Berlin Parliament have shown strong interest in attending, signalling their commitment to the issue of water management. This is particularly significant as Berlin is heading into an election year, and the workshop provides a timely opportunity to bring the issue of sustainable water management to the political forefront. By showcasing the model's practical applications and the implications of climate-induced water scarcity, we aim to push water management higher on the political agenda.

The commitment from key political stakeholders to attend this event is a major success, reflecting a growing recognition of the importance of water issues in the context of climate change. We are fully invested in making this workshop a success, as it represents a key opportunity to ensure that the scientific results of Task 4.7.1 are effectively integrated into the policy-making process, besides the successful uptake through practitioners. The outcomes of this workshop, including any commitments or follow-up actions, will be carefully documented and included in the final technical report of the project.

Workshop 3: Advancing Water-Oriented Forest Transformation in the Berlin-Brandenburg Region

This workshop is planned as an expert dialogue on water-oriented forest transformation in the Berlin-Brandenburg region. Originally foreseen for 2025, the event has been rescheduled to February 2026 due to the tight project timeline. The topic is of particular relevance for the region, as forest transformation towards mixed forests is a central measure in the Masterplan Wasser Berlin developed by the SenMVKU. Such measures aim to enhance groundwater recharge and thereby strengthen drinking water production, a crucial adaptation strategy in response to increasing water demand, declining precipitation, and more frequent droughts. The workshop aims to build a shared understanding among scientists, practitioners, and public authorities of what constitutes water-supportive land use, particularly in relation to sustainable forest restructuring and land management.

The event will include expert presentations on the hydrological effects of mixed forest development and lessons learned from long-term practical implementation (e.g., by Trinkwasserwald e.V.), followed by discussions among regional stakeholders from research, public authorities, and practice. These discussions will explore suitable terminology, region-specific characteristics, and research and development needs related to water-supportive land use and forest restructuring. A stakeholder analysis has already been conducted to identify relevant participants and ensure balanced representation from forestry, water management, and policy sectors. The workshop is expected to lay the groundwork for building a roadmap toward water-oriented forest transformation in the Berlin-Brandenburg region. The resulting roadmap will offer a basis for informing potential adjustments to the relevant measure of the Masterplan Wasser Berlin, ensuring that future implementation reflects the latest evidence and stakeholder perspectives and future project activities beyond IMPETUS.

2.2.2 Impact

Real-time, data-driven decision making:

- To demonstrate the model in this format showed its capability to simulate scenarios in real-time, helping to identify critical stress points within the Berlin water system when specific measures are implemented.
- This insight is crucial for prioritizing deeper analysis in decision-making processes and targeting interventions where they're needed most.

Stakeholder collaboration and knowledge transfer across sectors:

- Engaging key stakeholders, including the Berlin Water Utility (BWB) and the Senate for the Environment (SenMVKU), as well as a broader set of stakeholders, ensured a multi-faceted perspective on the challenges and solutions for the region's water management.
- The collaborative workshops created a space for stakeholders from various sectors to align their perspectives, fostering a shared understanding of the issues at hand.
- This transdisciplinary approach strengthened the understanding of regional water challenges and highlighted the need for integrated, cross-sectoral solutions.

Policy relevance and support for climate risk mitigation:



- The workshops successfully bridged the gap between scientific research, practitioners and policy, translating complex model results into actionable insights for policymakers.
- One of the most significant outcomes was the active participation of politicians for these topics, something that exceeded expectations. This political engagement has significantly raised awareness about water management issues and positioned the topic as a priority for the upcoming elections.

Visibility for the DS and the IMPETUS Project:

- The workshops and the overall task have significantly raised the profile of the Berlin-Brandenburg DS.
- By engaging the stakeholder and showcasing the applicability of scientific models to real-world issues, Task 4.18 has boosted the visibility and credibility of the IMPETUS project at the regional level.

2.2.3 Lessons Learned

Stakeholder engagement in the proposal stage

Bringing key stakeholders into the project from the beginning as partners ensured their active participation throughout the project. Effective stakeholder mapping and continuous engagement are critical for the success of their engagement.

Clear communication of model outputs

Presenting the results in a clear, accessible way that relates directly to stakeholders' needs and interests is essential for ensuring the model's practical application. The live calculation of different scenarios during the workshops was particularly impactful because the interest of further investigations and collaboration was sparked.

Building trust in scientific models

Demonstrating the accuracy and relevance of the Berlin Water Model through comparisons with existing planning tools (e.g., Masterplan Wasser) helped build trust and confidence in its predictive capabilities. Continuous validation and refinement of models, in collaboration with stakeholders, is essential for fostering long-term acceptance and use beyond the project.

Timing is crucial for political engagement

The high political interest in Workshop 2 was largely due to the timing, with Berlin's elections approaching. This emphasizes the importance of aligning scientific outputs with political cycles to maximize impact. Future projects should consider political timelines and the potential for leveraging upcoming elections or policy shifts to ensure greater engagement from policymakers.

Challenges of project partner transition

The transition from the initial task lead to KWB in early 2025 highlighted the risks associated with delayed deliverables and partner disengagement. However, KWB's swift adaptation and determination to meet deadlines ensured the success of the workshops and the continuity of the task.

EU support remains essential

The continued financial support from the EU was vital to ensure the timely completion of Task 4.18. Without this support, many of the key outcomes, including stakeholder workshops and scenario testing, would have been jeopardized.

2.2.4 Conclusion

The integration of stakeholder input, ensured the relevance of technical developments within the project (T4.7.1) to ongoing policy efforts, such as the Masterplan Wasser. The first workshops held has proven critical in translating these technical insights into actionable discussions, with significant political engagement expected in the upcoming workshop with political representatives. This has notably elevated the visibility of the DS and highlighted its alignment with the IMPETUS project and therefore EU Green Deal objectives, particularly in terms of climate resilience and sustainable water management. The lessons learned underscore the importance of early stakeholder involvement, adaptability in project execution, and the value of timing in aligning scientific results with political agendas, ensuring that the project's outcomes are both impactful and directly applicable to real-world water management challenges.



2.3 Co-design a Marine Spatial Framework (Task 4.19)

The Arctic faces key climate risks including **storm surges and sea-level rise**, **temperature changes affecting marine life**, and **increased precipitation** leading to **avalanches and landslides**. The **Marine Spatial Planning (MSP) framework** can visualize these risks by the integrated datasets such as sea-level projections, temperature trends, and terrain stability maps. This allows users to identify vulnerable areas, assess impacts, and plan adaptive, sustainable management of Arctic marine and coastal zones. The partners in the arctic demo site have co-designed a **Marine Spatial Planning (MSP) Framework of the coastal zone**, in form of a GIS-based environment able to integrate and display diverse data sources such as ocean variables, climate projections, marine traffic and spatial plans to support planning processes of marine areas.

Substantial efforts on the **development of the technical aspects** of the MSP framework have been made during the project months. In addition, stakeholder feedback and **online workshops** with several of the municipalities in the region was held. The overall goal was to help further identify and improve functionalities and the user experience to enhance the value/impact of the MSP framework. The feedback from the online workshop in December 2024 was important as it provided a good platform to show and demonstrate the usefulness of a high functioning MSP Framework. The feedback from this workshop is the basis for the sprints of development during 2025 in the project.

Key developments during the project period include:

- Established the **graphical design and user interface** for the MSP Framework.
- Identified and integration of key datasets relevant to the Arctic region.
- Stakeholder **feedback and development of key user-stories**.
- Publishing the MSP Framework with the first important functionalities
- **Established landing site** – functioning as a hub for the Marine Spatial Planning Framework and the digital twin of Tromsø city.
- Several **new functionalities** added to the MSP framework – including drawing features, background maps, new data layers on climate predictions.

In general, knowledge is still missing on understanding the **consequences of changes in water temperature** and other oceanic variables along the coastline. These changes are transforming marine ecological systems and posing a threat to fishing and aquaculture industries. However, these marine changes are incredible difficult to predict as there are many factors and variables involved. As such, the MSP framework has linked to tools and official governmental guidelines when applicable.

More specifically, some features and development of the MSP framework have been identified to address these challenges:

- New **ArcGIS story maps** on coastal environmental issues can be developed in cooperation with UiT to better inform the user on the changes happening along the coastline in Troms and Finnmark.
- Implementing further **collaboration features** between municipalities and the possibility to add your own data and information to the MSP framework.
- The MSP framework can provide a **overview of total biomass and health status on food fish** at aquaculture sites in the region - provided by our stakeholders and linked to the MSP framework.

The Marine Spatial Planning Framework in the Arctic demo site is a **strategic planning tool** that organizes the use of marine space to balance ecological, economic, and social interests. It integrates data on oceanography, biodiversity, resource use, and human activity to guide sustainable development. In the Arctic, where ecosystems are particularly vulnerable, this framework helps mitigate climate risks by **highlighting areas sensitive to warming temperatures and changes in biodiversity**. It supports proactive management and decision making based on **updated coastal and oceanic data**, such as salinity and temperature, which influence the distribution of marine species and ecosystem stability. Additionally, it helps **support policies and management** to reduce the risk of harmful algal blooms, which are becoming more frequent due to warming waters and increased nutrient runoff. By guiding development and conservation priorities, the framework enhances resilience in coastal communities and ecosystems, ensuring marine activities adapt to a changing climate in a responsible, science-based manner.

The Arctic demo site is undergoing significant changes in the coastal zone due to rapidly rising temperatures and shifting oceanographic conditions. Fisheries and aquaculture sectors must adapt to challenges such as biodiversity loss and species migration, as well as increased risks of harmful algal blooms and fish diseases. As climate change intensifies, the region is expected to experience greater precipitation, rising sea levels, and more frequent and severe storm surges—posing serious threats to coastal and marine infrastructure. Consequently, these developments endanger the livelihoods of both small and larger coastal communities across Troms and Finnmark.



The primary objective of this task was to co-design a Marine Spatial Planning (MSP) Framework tailored to the Arctic demo site, incorporating climate risk considerations and emphasizing the resilience and long-term sustainability of fisheries and aquaculture. The overarching goal is to equip local communities and businesses with tools and strategies for climate-related adaptation and intervention.

Main objective:

- Co-design a Marine Spatial Planning (MSP) Framework in our Arctic demo site, focusing on increasing the resilience and sustainability of fisheries and aquaculture.

Sub-objectives:

- Support coastal zone planning and sustainable management of fisheries and aquaculture.
- Reduce risk related to climate change on marine infrastructure, fisheries and aquaculture.
- Help mitigate the risk harmful algal blooms has on aquaculture sites and biomass.
- Inform the public on the dramatic changes that are happening in the Arctic and costal zones.

2.3.1 Results

During the early phases of the project in M8-M19, significant efforts were made to research possibilities and **identify needs, requirements, and limitations** of the MSP framework through close dialogue with municipal stakeholders and our technical partner. This included examining existing coastal plans, scientific papers, and reports. Several **meetings, interviews, and workshops** with key municipal stakeholders were conducted throughout the project. During these interactions, specific needs and requirements were identified, leading to the development of user stories for the MSP framework's development phase.

Following the initial stakeholder engagement, work commenced on **designing the MSP framework** based on the established user stories. In collaboration with UiT – the Arctic University of Norway – and our technical partner Geodata AS, the MSP framework was finalized. Subsequently, the main **development and technical phase** of the MSP framework began. This involved setting up servers, developing the ArcGIS client, and adding functionality and data. Moreover, substantial efforts were dedicated to **data assimilation**, as numerous datasets were gathered and processed from multiple sources and implemented into the MSP framework (<https://impetus.tromsfylke.no/app?view=2D>).

The MSP framework is now a powerful **ArcGIS map-client** that consist of several map services from governmental and local stakeholders that provide the user with data on regional costal plans, climate predictions on sea-level change, storm surge scenarios, and temperature and precipitation – all based on downscaled regional climate models following the IPCC models and reports. Several **maps and datasets** have been incorporated, allowing municipal planners and stakeholders to evaluate hazard maps, marine ecology, marine infrastructure, nature reserves, and other designated areas. This helps them consider climate-induced risks in the coastal zone and make more informed decisions regarding operations and spatial planning.

The MSP framework is connected to a **landing page** that serves as the homepage for the solution. This homepage offers **users story maps** that convey information on potential future changes in the coastal environment and their possible implications. The homepage also gives the user information about the IMPETUS project and the Arctic demo site. The homepage is available at <https://impetus.tromsfylke.no/> and is outlined in Figure 3. The user can easily navigate to the MSP framework by pressing the buttons at the top of the page.

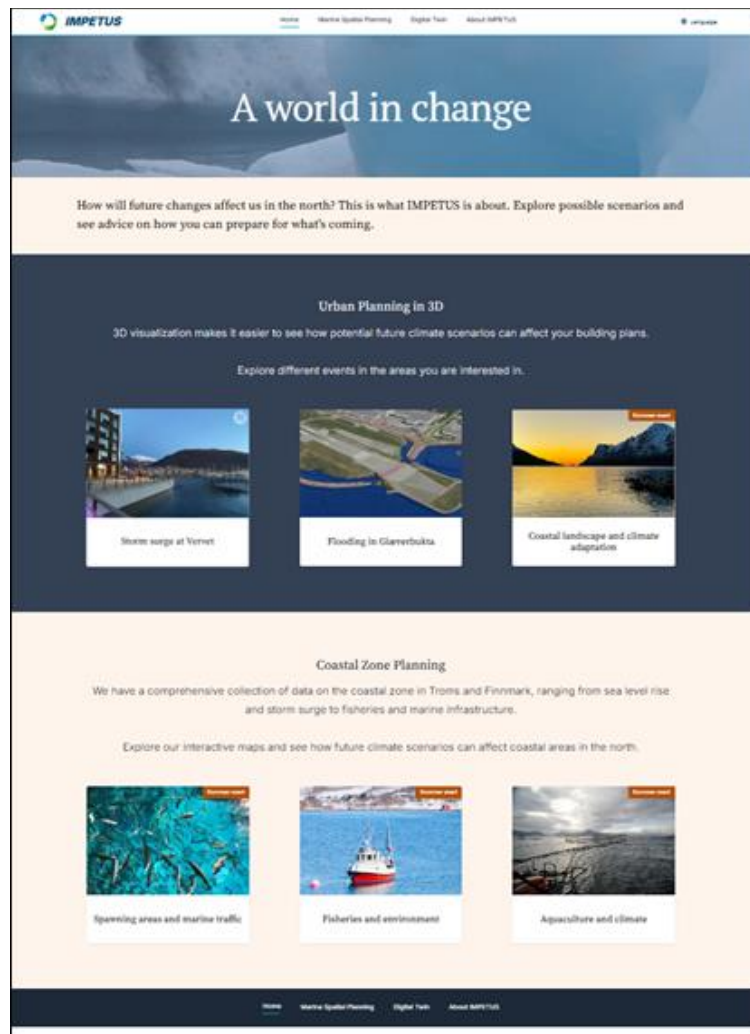


Figure 3: Overview of the landing page for the Marine Spatial Planning Framework. Also containing several story maps on important cases and studies about fisheries and aquaculture and climate. The homepage is available at <https://impetus.tromsfylke.no/>.

The MSP framework **supports decision-makers** to flexibly allocate or relocate fishery, aquaculture, and other marine operations to mitigate the risk of harmful impacts if needed. This is made possible as the solution combines **multiple datasets** on marine infrastructure, marine biology, and climate risks to provide a broad overview of relevant areas, climate risks, and operations in the coastal zone. In addition, the MSP framework contains data on the most important fishing areas and species in the region, based on their economic significance. It also includes information on fishing intensity along the coastline by method, as well as overviews of fishing, spawning, and breeding areas for key species. For aquaculture, it provides comprehensive details on localities and production intensity, disease indicators, and new area applications. The **user interface** of the Marine Spatial Planning Framework is depicted in Figure 4.



Figure 4: The MSP framework has an easy-to-understand user interface and contain several important datasets regarding climate change and associated risk in the Troms region. Integrated are also multiple datasets on fishery, aquaculture and marine infrastructure to provide the user with a full set of relevant data for marine spatial management.

Description and architecture overview of the MSP framework

The solution consists of a modern **web application** built with the following key components:

- The core technology is a JavaScript-based application. For modular functionality custom web components and responsive web design principles have been utilized.
- Most of the 2D map data are hosted and integrated from ArcGIS Online and external map services. For 3D visualization Web Scene and interactive 3D terrain including feature exploitation have been integrated to the MSP framework.
- A custom landing page have been made and integrated with Interactive narrative elements on climate issues and information about the demo site, using ArcGIS Story Maps.
- A custom analysis tools have been developed based on Interactive map-based queries, Integrated with Python-generated analysis layers.

Table 2: Overview of technical stack details.

Component	Technology
<i>Frontend</i>	JavaScript, Web Components
<i>Backend Services</i>	ArcGIS Online
<i>Map Services</i>	ArcGIS Web Maps, Web Scenes
<i>Analysis</i>	Python, Jupyter Notebooks
<i>Data Sources</i>	External Services, GeoDataOnline

Regarding specific findings, our work suggests the need for a **regional platform** to aid in coastal zone management decisions. The MSP framework meets this need, enabling data sharing, collaboration, and risk assessment in coastal areas. However, there is limited knowledge about climate change and its risks. The 21 municipalities show varying awareness levels, with smaller ones often lacking the expertise to tackle climate issues. We have therefore included central information on climate change in Troms to boost public awareness and engagement.

The development of this tool has been made possible through our close collaboration with Geodata AS and UiT – the Arctic University of Norway.

Several **workshops and interviews** have been conducted to develop the MSP framework, and include:

- Workshop with Tromsø municipality on needs and requirements and possibilities with the MSP framework.
- Interview with specific expert stakeholders from different municipalities in the region, including expert city planners and emergency preparedness.
- Presentation of the IMPETUS project the concepts, status and ambitions of the MSP framework was presented and discussed on the 2024 at the Business arena conference for municipalities in Troms County.
- Workshop with all municipalities in the Troms County working on coastal zone planning and interested in climate adaptation measures in the region.

2.3.2 Impact

Major achievements have been accomplished in the project with **several significant outcomes** directly addressing the main objectives of the task:

- Fully functional version of the MSP framework has been co-designed with key stakeholders and is online and openly available to the public stakeholders. Incorporating data to highlight risk and projected hazards associated with climate change in the coastal zone.
- The MSP framework includes data directly related to fishery and aquaculture activities together with regional coastal planes and climate hazards – supporting planning measures to mitigate risk in the coastal zone.
- The MSP framework includes information on how climate change affects our region and is predicted to have an effect on the coastal environment and infrastructure. This support public awareness regarding climate risks and the dramatic changes that occur in Troms.
- The MSP framework supports sustainable fishing in coastal fisheries by providing key data on fish living conditions and catch quantities.
- By including historical data on algal blooms and temperature predictions, users can make informed decisions about the reoccurrence of harmful algae.
- The MSP framework also helps mitigate risks related to climate-induced mass movements by offering updated maps of risk zones.

We have achieved **several of the KPIs** related to work with the Marine Spatial Planning Framework:

- The MSP framework has improved the planning foundations and collaborations between the county municipalities and other municipalities in the region through workshops, data sharing and collaboration features in the solution.
- The IMPETUS project and related work with the Marine Spatial Planning Framework had have a direct impact and long-term effect on the county municipalities and the Regional Plan for societal and climate Transition.
- The MSP framework has improved data sharing, awareness towards the importance of climate adaptation measures in the coastal zone in the municipalities in the region that will have a short to long-term impact.
- The long-term ambition is to integrate economic impacts and physical climate risks into the decision-making processes for policymakers in municipalities and counties.

2.3.3 Lessons Learned

Partners and stakeholders have acknowledged the **importance and benefits of a planning tool that integrates climate change risks** in the coastal zone. This was highlighted during stakeholder-developer dialogues, where key stakeholders articulated their needs and motivations. These discussions offered valuable insights for the county, municipalities, and other stakeholders. The integration of climate data and models towards traditional marine spatial planning data is therefore highly recommended.

Challenges encountered

- Major challenges ensued at the start of the project and extended until RP1. These challenges occurred due to loss of the initial project manager, lack of documentation and internal organization of the project. These issues were addressed by new personnel and an internal re-organization effort of the project around the RP1 period.
- Some challenges were encountered with the technical aspects during the development of the solution, particularly in integrating multiple map services, leading to performance issues. These challenges were addressed by scaling and manipulating the data.



- Challenges were also encountered in relation to stakeholder engagement and participation in the project. The reasoning for this is believed to be complicated and most likely is a combination of factors, including complexity of the project, language barriers, lack of capacity and knowledge.

Future recommendations

- A key recommendation for future projects is to establish a closer communication and co-creation partnership with key stakeholders from the outset. This would ensure that stakeholders have both the opportunity and capacity to engage and participate in the project, thereby minimizing the risk of stakeholder fatigue and loss of stakeholders.
- Another recommendation is for the EU to require beneficiaries to document how they are internally organizing and planning efforts when preparing for major projects like IMPETUS. This is especially relevant for governmental institutions such as municipalities and county municipalities. This will ensure a stronger internal foundation for the project and a clearer distribution of efforts among personnel.
- While significant progress has been made, there is a backlog of stakeholder-requested features and data, highlighting the need for expanded functionality. The usefulness of the tool will thus increase with time as more data and functionalities are added.

Barriers to transferability

The ambition is for this tool to become an integral part of the planning and decision-making process for municipalities in other regions with the same needs and requirements. There are no limitations on transferability. The solution is based on ArcGIS online technology and can be implemented by other municipalities at a national level and transfer internationally.

2.3.4 Conclusion

The development and implementation of the Marine Spatial Planning (MSP) Framework represents a **significant step forward in supporting coastal zone management and climate adaptation** in Troms and Finnmark County. Co-designed with key stakeholders and based on extensive municipal engagement, the framework effectively meets the project's primary objectives by **enabling informed decision-making through integrated spatial data**. As a publicly accessible, user-friendly ArcGIS-based solution, it brings together critical datasets on marine infrastructure, fisheries, aquaculture, and downscaled regional climate projections. This allows municipal planners and other stakeholders to assess climate-related risks – such as sea-level rise, storm surges, and temperature changes – while planning sustainable marine operations.

The MSP framework's impact extends beyond technical innovation. It aims to **fill a crucial knowledge gap in smaller municipalities**, many of which lack resources and expertise on climate change. By offering interactive tools, story maps, and region-specific data, it enhances public awareness and fosters proactive climate risk management. Furthermore, the tool supports sustainable fisheries and aquaculture by integrating biological and economic data essential for long-term planning.

This successful outcome was made possible through strong collaboration with UiT – the Arctic University of Norway and Geodata AS, and through outreach efforts including regional workshops and expert interviews.

2.4 Multi-purpose Controlled Environmental Agriculture (Task 4.20)

Resource management in the agricultural sector of Mediterranean regions presents a complex and pressing challenge due to a combination of environmental, economic, and social factors. **Water scarcity** is a key issue, as water is the most critical and contested resource in Mediterranean agriculture.

The Attica region is characterized by:

- **Seasonal rainfall and droughts:** long, dry summers and irregular rainfall patterns reduce water availability.
- **Over-extraction of groundwater:** to compensate for limited surface water, aquifers are often overused, leading to depletion and salinization.
- **Inefficient irrigation:** traditional irrigation practices can waste significant amounts of water. Although drip irrigation is increasingly used, adoption varies widely.

Furthermore, the Mediterranean regions, such as Attica, are climate change hotspots, in which heatwaves, unpredictable rainfall, and storms affect crop yields and sustainability of the agricultural sector. Inefficient agricultural practices and intensive agriculture threatens biodiversity. Efforts to improve resource management include innovation and sustainable practices that mainly focus on



precision agriculture with the use of technology **for more efficient water, materials and energy use**. In conclusion, sustainable resource management in Mediterranean agriculture requires an integrated approach that considers environmental limits and fosters resilience to climate change. **Collaboration** between governments, researchers, and local communities is essential to implement effective policies and practices.

Controlled Environmental Agriculture (CEA) solutions refer to agricultural systems where vegetable, ornamental crops or even fruits are cultivated in indoor environments where, with the use of the appropriate equipment, the crop microclimate is monitored and regulated in order to have better yields, of higher quality, and larger market availability (Vatistas et al., 2022). However, in most of the cases the CEA solutions can be environmental unfriendly specially where there is a large concentration of greenhouses, leading to over-abstraction and depletion of groundwater, as well as deterioration of groundwater quality, increased salinity concentrations (due to the increased irrigation demand) and huge amount of disposed wastes (due to the irrational use of agrochemicals). The above situation has generated the need for **sustainable agricultural practices and innovative tools** so as pollution is minimized, better use of resources is achieved and societal needs are satisfied, without compromising crop performance and quality.



Figure 5: Typical Mediterranean greenhouse.

This particular CEA solution is an **innovative decision support system**, implemented in a typical Mediterranean greenhouse establishment, that attempts to monitor the system through a dedicated **network of sensors**, and **provide recommendations** for the farmers, so that resources efficiency is increased and the resilience and sustainability of the Attica region and its adjacent natural habitats is enhanced.

This solution serves as a **proof of concept** for the development and implementation of innovative, sustainable technologies in greenhouse farming. Specifically, this decision support system enables users to define the ideal microclimate parameters for their selected crops, utilizing a combination of sensors, actuators, and intelligent network systems. By leveraging **integrated machine learning tools**, the system provides tailored recommendations for optimal equipment adjustments, so as to achieve the desired conditions. This empowers agronomists to monitor dynamic environmental factors and take corrective actions when necessary to maintain optimal cultivation conditions. These solutions not only **improve precision in greenhouse operations** but also **enhance energy and water efficiency**, supporting sustainable farming practices.

In the framework of IMPETUS, the demo site partner intentionally choose a **hydroponic system** established in a greenhouse, named **Attica Green**, in a peri-urban area with many environmental constraints (high salinity water, close to the airport). Attica Green, located in Spata, in the eastern region of Attica, serves as the test site for this initiative. The facility, which houses a series of greenhouses producing high-quality, eco-friendly products, was selected by the IMPETUS project to **test and validate the decision support solutions for Controlled Environmental Agriculture**.



Figure 6: Attica Green facility – Tomato crops.

The demo set up was accommodated in a 0.2 ha greenhouse made of galvanized steel frame and twin wall polycarbonate glazing. The greenhouse employs some **energy conservation methods** that are briefly described as could be critical in our set up. Firstly, natural ventilation is achieved through the opening of windows at the top and the sidewalls of the greenhouse. This allows the hot and humid air which builds up at the top of the greenhouse to be evacuated. Secondly, the use of thermal curtains (fabrics with aluminium stripes woven into them, that are placed between the crop and the greenhouse roof) may save energy in multiple ways. In cold weather, they reduce the heat loss by trapping the warm air between the curtain and the crop. Moreover, aluminium curtains reflect the infrared radiation emitted by the crops and the overall structure, deflecting it from escaping through the roof. Curtains can also be used during summer for shading. Another system that the greenhouse uses is the fan and pad, which is comprised from a fan in the one wall and a wet pad on the other side. In this way, the outside air is sucked, humidified and cooled through the wet pad and as the cooled air moves through the indoor environment captures the heat which is removed by fans on the opposite end.

2.4.1 Results

For developing the CEA solution, after the site selection, a series of activities were implemented as described below.

1. Sensor installation and data logging

IoT-enabled sensors were successfully installed in the selected greenhouse, Attica Green, to monitor critical environmental parameters such as temperature, humidity, light intensity, and soil moisture. These sensors provide **real-time data** that is essential for maintaining optimal conditions for plant growth. The collected data enables the identification of trends and fluctuations, forming the basis for **predictive modelling and automated adjustments**. This not only enhances operational efficiency but also reduces resource consumption, contributing to the overall sustainability of greenhouse operations. Following sensor installation, a **data logging platform** was developed to interface with the greenhouse systems. This platform serves as the central hub for all collected data, facilitating seamless communication between the greenhouse's IoT devices and the digital twin system. It ensures smooth data transfer from the sensors to the platform, where it can be stored, analysed, and utilised by predictive models and decision-support tools. The recorded data allows users to **monitor critical indicators** for greenhouse management in real-time. Specifically:

- **15-minute updates:** changes on the conductivity and pH of the nutrient solution's output water are recorded every 15 minutes, providing a detailed view of its current status.

- **External conditions:** data on external temperature, humidity, and rainfall are displayed, enabling an assessment of environmental factors that may impact crop growth.
- **Greenhouse microclimate:** measurements of temperature and humidity within the greenhouse, offer insight into the internal environment that directly affect plant development.
- **Equipment status:** detailed information on the operation of shading curtains, windows, and cooling fans is available, supporting optimal management of lighting, ventilation, and temperature.



Figure 7: Monitoring and control unit.

This comprehensive dataset enables advanced analytics and informed decision-making, ultimately enhancing agricultural productivity and resource management.

- **New sensors:** data recording started in May 2024.
- **Existing datasets:** include historical data from 2022, providing a broad temporal range for analysis.

2. Development and training of the Random Forest model

Leveraging the historical data collected from the sensor installations, a Random Forest model was trained to **predict optimal settings for the greenhouse's microclimate control systems**, such as windows, fans, and curtains. The model relies on key environmental variables, including temperature, humidity, and radiation levels to recommend adjustments that balance energy efficiency with ideal growing conditions for crops. The model's predictive accuracy significantly improved thanks to the rich dataset, combining both **historical and real-time sensor data** collected across multiple seasons. This diverse input allowed the model to better capture complex patterns in the environment. Additionally, the application of feature engineering further refined the environmental variables, enhancing the model's precision and robustness. As a result, the system now autonomously adjusts greenhouse settings based on real-time data.

How it works

The system utilises Random Forest regression, a powerful machine learning technique, to analyse and predict the optimal settings for the greenhouse's climate control systems. The process consists of:

- Data collection:**
Greenhouse interior: monitors temperature, humidity, and radiation levels.
Rhizosphere (substrate): tracks substrate humidity and temperature.
- Data processing and prediction:**
The collected data is fed into the Random Forest model, which processes both historical and real-time inputs to calculate the optimal settings for windows, curtains, and fans. The algorithm accounts for non-linear interactions between variables, making it highly effective in dynamic and complex environments.
- Recommendation and adjustment:**

Based on the model's predictions, the tool recommends adjustments to ensure the microclimate stays within the user-defined thresholds. These recommendations are continuously refined as new data is collected, improving the model's accuracy over time.

3. Integration of the intelligent recommendation tool with IoT systems

The integration of the intelligent recommendation tool with the greenhouse's IoT systems offers **real-time automated recommendations** for adjusting systems like windows, fans, and curtains. The tool also focuses on refining its capacity for autonomous recommendations and adjustments, which are expected to reduce manual intervention, optimize plant growth conditions, and minimize energy consumption. The tool is an **innovative decision-making system** powered by machine learning algorithms, specifically Random Forest regression, to optimise greenhouse operations. It stands out for its ability to handle complex, non-linear relationships between environmental factors and system adjustments. Its primary goal is to maintain an ideal microclimate tailored to the specific needs of each crop, based on user-defined temperature and humidity thresholds.

Data collected from the greenhouse along with the Random Forest model are integrated in the **Attica Digital Twin platform** (T4.10.4), see Figure 8, as the system has been designed to ensure interoperability, enabling real-time data collection and analysis from the sensors within the Digital Twin framework. It provides users with a comprehensive view of both live and historical data for the hydroponic greenhouse. It grants access to all recorded time-series variables, including detailed measurements of environmental conditions, nutrient solution parameters, equipment status, and any other critical indicators being monitored. Users can analyse trends, correlations, and patterns over time, gaining deeper insights of the factors that impact crop performance. This section is designed to support advanced data visualization and export features, simplifying the interpretation of complex datasets. By leveraging these insights, users can refine their strategies, optimize greenhouse operations, and improve overall productivity and sustainability.

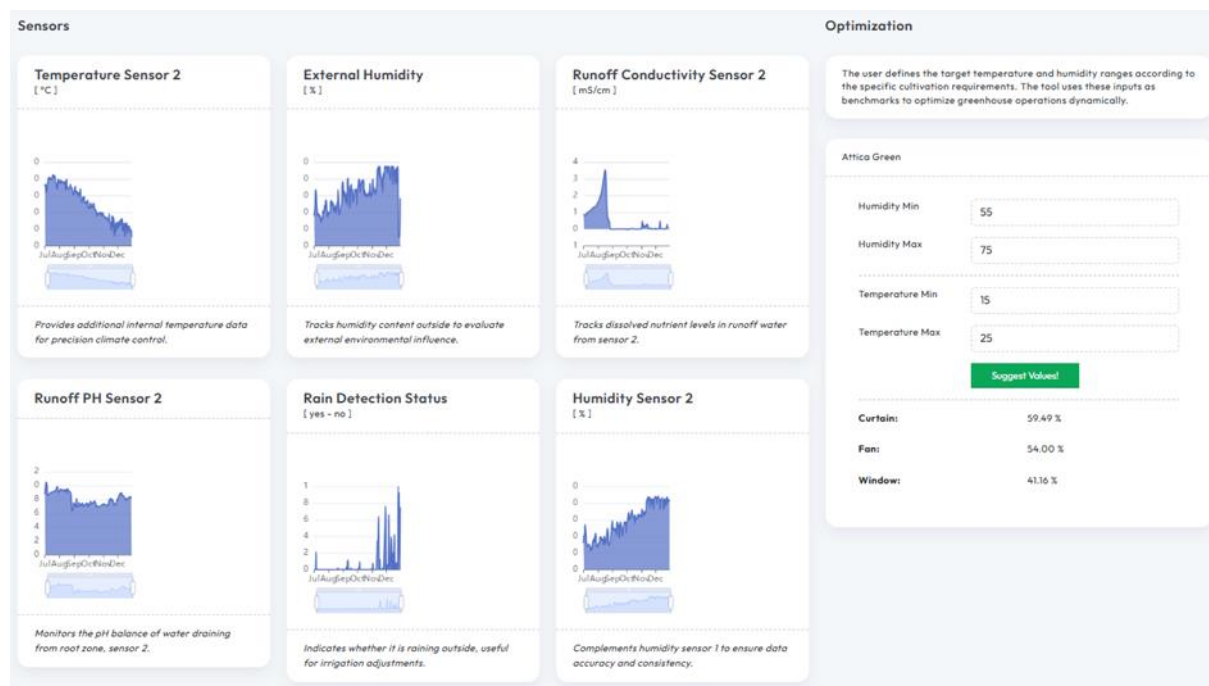


Figure 8: Attica Digital Twin platform – Real time monitoring system and recommendation tool for optimal greenhouse operation.

4. Final design of the system

The final design phase of the Controlled Environmental Agriculture (CEA) system focused on **customizing the solution** based on the Attica Green site through **collaboration among project partners**. Feedback from stakeholders and technical assessments were incorporated to refine the design, optimizing efficiency and sustainability for local conditions. Key parameters were identified for monitoring temperature, humidity, light intensity, CO₂ levels, etc. and suitable sensors and control mechanisms for system integration were connected.

2.4.2 Impact

Based on the results presented above, the main impact of the CEA solution can be summarized as follows.

Improved precision in greenhouse management

- The system allows for real-time monitoring and precise control of environmental factors such as temperature, humidity, light levels, and CO₂ concentration. This precision ensures optimal conditions for plant growth, improving crop yields and quality.
- By analysing large sets of data, the system can predict potential issues before they occur, such as pest outbreaks or nutrient deficiencies, enabling proactive management and reducing crop losses.

Energy efficiency

- The integration of CEA technologies with a system can lead to more efficient energy use within the greenhouse. The system can optimize lighting, heating, and cooling based on the specific needs of the plants and the current environmental conditions.
- By reducing unnecessary energy consumption and making the most of renewable energy sources, the greenhouse can reduce operational costs and carbon emissions, contributing to the sustainability of the farming operation.

Water efficiency

- Water management is a critical concern in greenhouse farming, especially in regions with limited water resources. The system can monitor soil moisture, plant water usage, and evapotranspiration, enabling precise irrigation control.
- This leads to reduced water waste, as the system can ensure that crops receive just the right amount of water at the right time, supporting sustainable water use and reducing the risk of over-irrigation or water shortages.

Sustainable cultivation practices

- By optimizing inputs like water, nutrients, and energy, CEA systems promote sustainable cultivation practices that reduce the environmental impact of farming.
- The system can also integrate data on soil health, pest management, and crop rotation to encourage practices that maintain and even improve soil quality over time, reducing the reliance on chemical fertilizers and pesticides.

Proof of concept for scaling and adoption

- The pilot system serves as a proof of concept for larger-scale adoption of CEA solutions in greenhouse farming. Successful demonstration of these technologies can pave the way for wider implementation in both commercial and small-scale farming operations.
- It also provides valuable data and insights that can inform future innovations in greenhouse farming, pushing the boundaries of what is possible in terms of sustainability, efficiency, and crop production.

Economic and environmental benefits

- The combination of increased yields, reduced input costs (water, energy, fertilizers), and reduced environmental footprint makes the greenhouse operation more economically viable and environmentally responsible.
- By improving the sustainability of greenhouse farming, the system can contribute to the long-term resilience of the agricultural sector, particularly in the face of climate change and resource scarcity.

In summary, the impact of a CEA solution through a pilot system is multifaceted. It enhances greenhouse management precision, improves energy and water efficiency, supports sustainable farming practices, and provides a scalable model for future agricultural innovation. This can lead to higher productivity, lower environmental impact, and greater economic sustainability in greenhouse farming.

2.4.3 Lessons Learned

The benefits of the decision support tool are summarised below.

1. Innovation in optimization

The tool uses **Random Forest regression**, a machine learning method that can handle complex, nonlinear relationships between environmental variables (like light, temperature, humidity) and crop



growth. Thus, it can **predict optimal growth conditions** more accurately than traditional rule-based or linear models. Furthermore, the Random Forest handles large datasets and noisy data well, which is common in real-world agricultural environments. This approach enables **data-driven optimization**, a cutting-edge alternative to trial-and-error farming, and therefore controlled agricultural systems i.e. greenhouses can adopt a **scientifically backed, innovative approach** to boost productivity and sustainability.

2. Increased efficiency

The tool maintains ideal growing conditions by continuously analysing data and adjusting environmental parameters. The tool provides a constant optimization that leads to higher crop yield and quality with fewer inputs, it reduces downtime or poor growth phases caused by suboptimal conditions and helps in scaling precision agriculture without requiring constant human monitoring. In summary, there is an improved resource allocation, faster crop cycles, and better consistency in production.

3. Cost savings

With accurate predictions, water, energy, and other inputs are only used when truly needed. Therefore, water usage is reduced by irrigating based on real-time crop needs, and energy costs drop since heating, cooling, or lighting is optimized rather than run on fixed schedules. Also, this system helps prevent overuse of fertilizers or other costly inputs. There is overall significant operational savings that improve profit margins while promoting environmental responsibility.

4. Customization

The tool can be configured to support various crop types and their specific growth requirements.

- Farmers can **input their own parameters** or allow the model to learn from crop-specific data.
- Adaptable to local climate conditions, soil types, and other farm-specific constraints.

Overall, the system enables **personalized precision farming**, which is more effective than one-size-fits-all solutions.

5. Reduced errors

Automation and intelligent decision-making reduce the chances of mistakes due to human oversight.

- Eliminates manual guesswork, reducing human error in adjusting environmental controls.
- Avoids costly mistakes like overwatering or improper lighting duration.
- Ensures consistency, even when experienced personnel are not available.

In total greater **reliability, predictability, and ease of use** in day-to-day farm management is achieved.

2.4.4 Conclusion

The primary goal of this initiative was the testing and validation of a Controlled Environmental Agriculture (CEA) solution through a pilot Decision Support (DS) system that was developed in the scope of the project, with the aim of enhancing the resilience and sustainability of the Attica region and its surrounding natural habitats. To achieve this, an integrated network of sensors to record and collect data from the crop environment was designed and implemented. These data flows, capturing conditions in the rhizosphere, the plant, and the greenhouse microclimate, are visualized through a Digital Twin platform in a clear and accessible manner. This enables precise monitoring of crop needs and supports the optimization of resource use, including water, energy, and fertilizers.

By applying advanced software analysis, algorithms, and IoT technologies, a tool was developed to provide recommendations to the greenhouse operators on the use of windows, fans and curtains, so as informed decisions are made precision irrigation practices are implemented. This tool was also validated and optimised through data monitoring and observation. The entire system can also activate automation processes, seamlessly integrating with the existing infrastructure and equipment of the Attica Green greenhouse facilities. In doing so, the system not only ensures efficient and sustainable cultivation management but also strengthens overall resilience. The project serves as a proof of concept for the application of innovative, sustainable technologies in greenhouse farming. In particular, the optimisation tool allows users to define ideal microclimate parameters for their crops and, with the support of integrated machine learning tools, provides tailored recommendations for equipment adjustments. This functionality improves the precision of greenhouse management, enhances energy and water efficiency, and promotes sustainable cultivation practices.

2.5 Activating Cultural Heritage to enhance climate resilience (Task 4.21)

This task supports the objectives of WP4 by identifying both technological and non-technological solutions that merge local, sectoral, and innovative knowledge. The goal is to provide decision-makers with practical tools for planning climate adaptation strategies, while also enabling the transfer of these approaches to other regions. The focus is on showcasing how **cultural heritage can enhance climate resilience**, particularly in the **agricultural and built environment sectors**, through a combination of **traditional practices and innovative solutions**. This dual research approach values cultural heritage as a dynamic process – both preserving adaptive traditions and exploring newly developed strategies – offering valuable insights for policymakers and future research.

Overview and latest developments

The area of Valle dei Laghi (DS7) and the Province of Trento have a long history of **agriculture and wine production** and have a building stock characterised by homogenous construction techniques and concentration of **built heritage** in towns centres. These same **elements of identity** are now threatened by the effects of climate change. The current climate situation is not yet severe enough to irreparably damage these elements, but it remains a significant threat in the shared perception.

Among the stakeholders and communities, there is a consensus on the necessity to transition towards adaptation measures. The observed climate phenomena are observed at the local, provincial, and European levels. Therefore, there is a shared opinion on the need to respond to these phenomena through progressive adaptation actions. Specifically, the following **climate change impacts** have been observed:

- Extreme weather events such as frosts, extreme hailstorms, more intense and concentrated rainfall, heat waves, and proliferation of parasites and fungal diseases.
- Summers are getting increasingly hotter.
- Significant repercussions on the local sector and heritage, with direct consequences for the integrity of the products and on the liveability of the building stock.
- The need to establish appropriate agronomic and management choices.
- The need of outline strategies and technical solutions to keep historic buildings comfortable despite climate change.

This task aims to investigate solutions derived from tradition and local knowledge, while also considering new scientific developments (a dual path between tradition and innovation).

Main gaps identified

- The increasingly intense and extreme weather events bring the need to seek new potential adaptation solutions in the viticulture sector, which is facing unprecedented challenges.
- The involvement of cultural heritage in the search for climate change adaptation solutions is a recent and under-explored topic, mainly for intangible aspects of heritage, although its importance is repeatedly emphasized in numerous international instruments.
- The recovery of traditional practices is fundamental alongside more innovative solutions in developing optimal adaptation strategies.
- Numerical simulation of the built environment brings several challenges when it comes to the generation of accurate results. For instance, building dynamic simulations need hourly climate data, while usually future climate data are generated with a daily resolution.

Task objectives and motivation in the project

- Investigate how and if culture can influence the search for adaptation solutions.
- Research culture-based solutions applicable to the demo site and transferable to other contexts, aiming to develop climate change adaptation solutions that consider the cultural, value-based, and identity dimensions of cultural heritage.
- Propose a research initiative that integrates local territory and community members. This involves selecting and engaging a sample of stakeholders from the agricultural, wine-making, and academic sectors, identified at both the demo-site and European levels.
- Present solutions that are both energy-efficient and sustainable for the environment, the territory, and the community.
- Present the widest possible range of adaptation solutions, drawing on the recovery and progressive development of traditional knowledge, and to encourage further debate and research on the topic.
- Raise awareness of behaviour strategies that help to reduce summer discomfort and so maintain buildings liveable.

- Drive local authorities to enable adaptive solutions for built heritage and support local agricultural firms in the transition through adoption of adaptation solutions.

2.5.1 Results

Intangible cultural heritage

This part of the task identified and assessed culture-based adaptation practices currently implemented in the demo site, with a particular focus on their potential for transferability. The research also proposed adaptation measures specifically relevant to the viticulture sector. This was done through **12 interviews and 2 questionnaires** to relevant stakeholders. Main outcomes are the following:

- **Synergy between tradition and innovation:** there is strong collaboration between historic winemaking companies and research centres, demonstrating how traditional knowledge and technological innovation can complement each other in adapting viticulture to climate change.
- **Orientation towards organic viticulture:** a clear trend toward organic farming emerges, driven by environmental and health concerns. Traditional practices are combined with innovative techniques to increase biodiversity, improve soil quality, and develop disease-resistant rootstocks. This approach strengthens the resilience of plants and aligns with environmental commitments (e.g. Ferrari Protocol, Torres & Earth).
- **Smarter phytosanitary treatment use:** although treatments are still necessary, there is a move towards more conscious, targeted use supported by technology (e.g. QR tracking, AI, projects like COPPEREPLACE and LIFEisLIGHT) to avoid overuse and improve plant health.
- **Interest in alternative grape varieties:** producers are exploring more resistant or ancient grape varieties to reduce water and treatment needs. This transition must be accompanied by a broader cultural discussion on the inclusion of these varieties (e.g. Piwi) in quality labels and appellations.
- **Altitudinal shift of vineyards:** the practice of relocating vineyards to higher altitudes is gaining attention to mitigate climate effects and reuse abandoned land. It offers aromatic advantages but also poses challenges (e.g. frost risk, water access, labour intensity). Pilot actions and further research are ongoing.
- **Efficient irrigation management:** a mix of traditional observation techniques and modern tools (e.g. Winegraft, AWC, SWAB, IRRITRE) supports smarter irrigation. The goal is to develop root systems and optimize water distribution, promoting a Soil-Plant-Atmosphere system for sustainable resource use.
- **Soil health and organic matter:** soil quality is increasingly recognized as key to healthy, resilient vineyards. Emphasis is placed on aeration, fungal-resistant species, and new rootstocks that ensure efficient water and nutrient uptake.
- **Risk management and insurance:** there is shared use of anti-hail nets, insurance policies, and agro-meteorological services to manage climate risks like hail and frost. Technological solutions are being explored for frost protection.
- **Reducing carbon footprint:** efforts are underway to reduce emissions through sustainable packaging, monitoring, and carbon offsetting. There is also widespread commitment to cultural heritage preservation and the protection of traditional knowledge.
- **Cultural and landscape preservation:** viticulture is seen not just as production but as a cultural and environmental heritage. Companies are committed to protecting the landscape and reaffirming the role of the farmer as a land steward.

Tangible cultural heritage

Taking in consideration climate change while renovating a building now it is key. Winters will most probably remain part of future climate scenarios; therefore, well established solutions can play an important role for increasing occupants' comfort in winter and save energy and carbon emissions.

- **Insulation of building envelope:** external or internal. Different options were investigated from both energy and moisture safety point of view. Both approaches would work for the climates and for the specific simulated building.
- **Substitution or improvement of existing windows:** controlling heat losses in winter.
- **Mechanical ventilation with heat recovery:** crucial for the further reduction of energy demand.

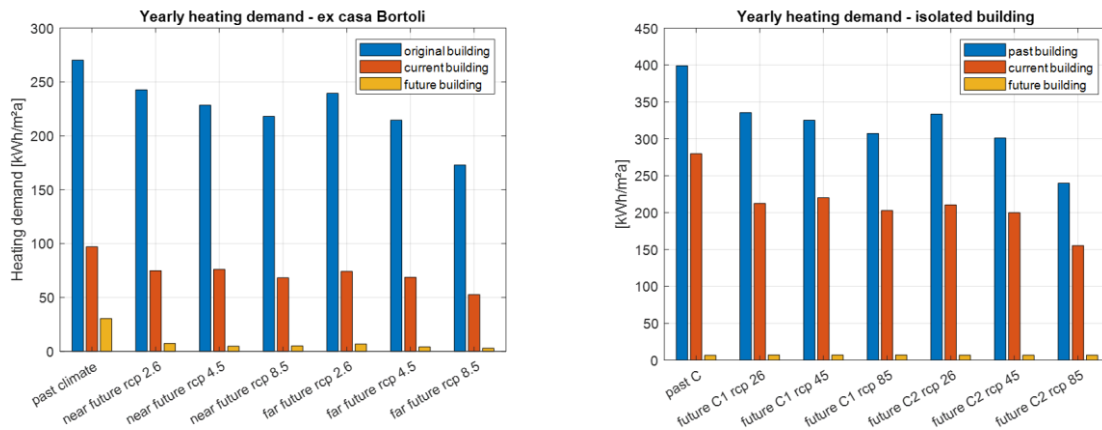


Figure 9: Yearly heating demand for original, current and future building for past and future climates for ex casa Bortoli on the left and for the isolated building on the right.

In Figure 9 it can be seen the yearly heating demand for all seven scenarios considered (past climate, near future with three emission scenarios, far future with three emission scenarios) for three configurations of the building (original, current and future building) and for the two simulated buildings. It can be noticed that not retrofitted buildings (blue bars) have a very high energy demand for space heating even in the most pessimistic scenarios of climate change with increasing temperatures (with much higher energy demand for the isolated building, because the dispersing surface is much bigger than the surface in the aggregated building). Already a **minimal renovation helps significantly in decreasing the energy demand**. The “future building” scenario considers a combination of all developed renovation strategies implemented and brings to huge savings and zeroes the difference between the two buildings.

Temperatures are increasing and this leads to more summer discomfort in buildings resulting in the need for additional active cooling systems. To prevent this, the following adaptation strategies for summer were simulated:

- **Shading during the day** is fundamental to reduce summer discomfort. To plan a shading device when renovating now is necessary to enable the renovation to last also in future climate. This is also building on traditional strategies for adaptive comfort that are compatible with the conservation of the built heritage.
- **Opening the windows during the night**, when the temperature outside decreases, is necessary to cool down the inside air and the building mass. This strategy relies heavily on occupants understanding of the benefits and engagement in the building operation.

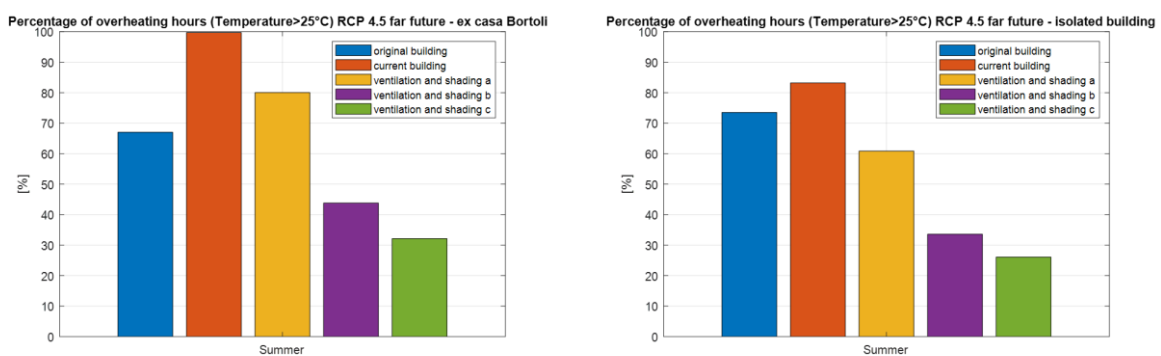


Figure 10: Percentage of overheating hours (temperature>25°C) in summer for original and current buildings and different ventilation and shading strategies for ex casa Bortoli on the left and for the isolated building on the right.

In Figure 10 is presented an example of results for the RCP 4.5 scenario in the far future, the percentage of overheating hours in summer for both simulated buildings. It can be noticed that the different ventilation and shading strategies (a, b, and c) bring to an important decrease in summer discomfort. The attic of historic buildings in Valle de Laghi often presents round opening, because the space was usually not lived and used for storage of hay during wintertime. In summer, these holes enabled cross-ventilation through the attic and lowered the temperature in the flat underneath. However, the result of

the simulations show that this effect is not visible anymore in the current or future building because of the thermal insulation added on the intermediate floor between the last inhabited floor and the attic. Since the heat losses are minimised for winter, the potential for heat exchange between flats and attic in summer is negligible. Furthermore, results highlighted that in order to reduce the heating demand per square meter, it is convenient to **inhabit most of the building volume possible** including the attic, because of the ratio between the volume and the thermal envelope of the building.

It is often claimed that summer discomfort will worsen when applying internal wall insulation. This was studied in detail by means of the simulations. Internal insulation and external insulation result in different behaviour of the building in summer, but the difference between the two is minimised by the presence of internal partitions, which are an important contribution to the thermal mass of the building. With internal insulation the hours of discomfort are more concentrated in the afternoon/evening hours, while with external insulation the temperature fluctuates less during the day. In any case, there is only a **slight difference between the two types of insulation when it comes to the total sum of discomfort hours**.

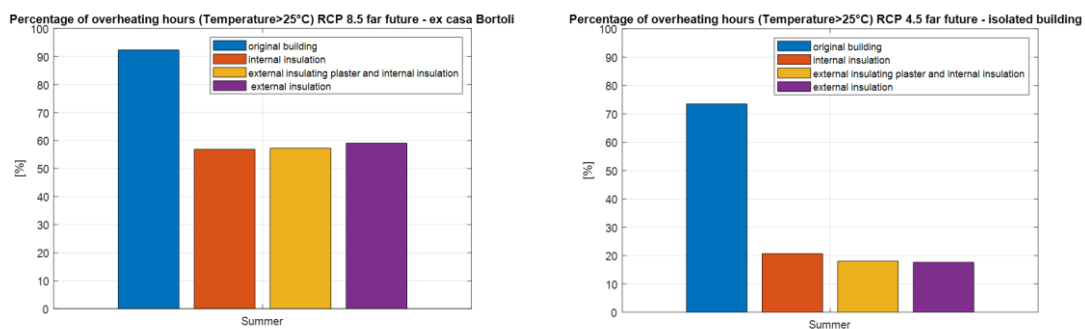


Figure 11: Percentage of overheating hours in summer (temperature > 25°C) for original building and different renovations strategies (internal insulation, external insulating plaster and internal insulation and external insulation) for ex casa Bortoli on the left and for the isolated building on the right.

The percentage of overheating hours in summer for the RCP 8.5 in the far future is depicted in Figure 11 for both simulated buildings. The different types of insulation show only a slight variation in summer discomfort.

Methods, tools and techniques

Intangible cultural heritage

- Analysis of the literature and the main binding and non-binding international instruments on intangible cultural heritage.
- Survey and interview methods were employed:
 - For the collection of perceptions (Phase 1):
 - An anonymous, general, non-specific sample of residents of the Valle dei Laghi was involved through a qualitative survey disseminated via the internet.
 - Exploratory survey to confirm the trend already highlighted by a survey at the beginning of the project and what emerged during various engagement events.
 - Stakeholders from the institutional, associative, agricultural and winemaking sectors of the demo-site and Trentino area were involved through anonymous, semi-structured qualitative interviews.
 - To collect a set of adaptation solutions (Phase 2 of the work):
 - Local and European stakeholders were involved through semi-structured qualitative interviews.
 - The agricultural, winemaking, and academic sectors were involved (Ferrari Trento; Fratelli Pisoni; Jean Leon; Edmund Mach Foundation).

Tangible cultural heritage

- Analysis of existing building stock:
 - Territorial analysis of the area based on historical maps development and on-site visits.
 - Digitalization of building evaluation and description sheets for two historical centres of the valley from a previous work.
 - Statistical analysis of the building stock base on the building sheets.
 - Individuation of representative buildings.

- Analysis of past and future climate:
 - Analysis of different weather stations of the valley in order to identify the most representative climate. The analysis was done calculating the worldwide defined climate indexes.
 - Comparison between past/present and future climate using the same indexes.
- Dynamic building simulations on two representative buildings, both situated in Calavino village:
 - First simulated building: an aggregated, residential building: the so called “ex casa Bortoli”. It dates back to the early 1700s, and features typical construction methods: stone masonry, vaulted cellars, wooden roof, ventilated attic space, stone window and door frames. The building has four storeys und was renovated in 1996, where the building envelope performance was minimally improved and the attic was converted into an additional dwelling.
 - Second simulated building: an isolated residential building built before 1860. It also includes traditional construction methods, such as stone masonry, vaulted cellars, wooden roofs, attic openings, and stone window and door frames. It was minimally renovated in 1985. Although isolated buildings are less common in the historic centres of this area, their importance in the configuration of towns and significance make it important to understand their behaviour.



Figure 12: On the left ex casa Bortoli, on the right the isolated building.

- Simulations on original building and current building under all climate conditions and analysis of results were carried out.
- Starting from these results, development of adaptation solutions and validation based on simulation results.
- Simulations on future building, as result of the sum of renovation strategies developed.
- Analysis of results of simulations in terms of summer and winter discomfort, energy demand and hygrothermal behaviour of the wall.

Collaborations

- Close collaboration among project partners to reach European stakeholders; collaboration with local institutions to disseminate the questionnaire and gather perceptions on the need for adaptation solutions.
- Collaboration with Lobelia for modelling future climate data, presentation of results to local politician and cooperation with them for dissemination.

Publications and other outreach activities

- Conference Paper: “The urgent call for tangible actions to adapt regions to climate change impacts: the example of IMPETUS mountain demonstration site” – DOI:10.2495/SDP240751.
- Conference Paper: “Future climate adapted renovation measures for historic buildings: a case study” at EEHB 2024 in Krems, Austria.
- Conference Paper: “Investigating Different Insulation Strategies for Present and Future Climates in Winter and Summer Conditions” at CESBP 2025 in Budapest, Hungary.

2.5.2 Impact

Impact and response to task objectives

- The presented results aim to highlight potential adaptation solutions to climate change in the context of viticulture and built heritage.
- The research approach responds to the project's requirements by finding culture-based adaptation solutions and evaluating how local perceptions contribute to incentivizing and supporting the development of future adaptation solutions.

- The highlighted adaptation solutions from the demo-site meet the transferability objective, demonstrating how the chosen direction is also shared by actors from different territorial and climatic areas.
- The range of solutions identified is a product of merging the firsthand experience of field practitioners with the scientific expertise of researchers.
- In the case of the built heritage, the approach chosen combines field work, statistical analysis of the building stock, and numerical simulation to develop strategies that are then discussed with local stakeholders for their adoption and dissemination.
- The research approach, which seeks to engage local individuals and communities, is in line with the guidelines set forth by international instruments on cultural heritage and climate change.
- While presenting a range of potential and exportable adaptation solutions, the research approach does not aim to find exhaustive, definitive, or universally applicable answers for every territorial or climatic area. Rather, it seeks to stimulate the future and progressive development of adaptation solutions that take into account the specific territorial and cultural characteristics of individual places, while carefully proposing adaptation solutions that respect the environment, the common cultural heritage, and the present and future generations.

Time-scale effects

- The presented solutions are applicable in the short to medium term.
- Long-term applicability is difficult to predict due to the worsening of climatic conditions:
 - Some solutions remain valid and applicable even on a potential long-term timescale.
 - It is necessary to encourage research and dialogue to promote the constant evolution of adaptation solutions.
- It is necessary to start considering or sharing current adaptation solutions to mitigate the impacts already present:
 - Contribute immediately to reducing the environmental footprint of human activities.
 - To take proactive measures to avert potential direct damage to cultural heritage assets.
- The analysis of the tangible heritage has combined both time-scales as part of a win-win strategy. While in the short term, proposed intervention for retrofit of historic buildings contribute to the reduction of the carbon emissions and climate change, in the long term, the same solutions ensure increased occupants' comfort and conservation of the built heritage.

Role of the task

- Reiterate the importance of cultural heritage in contributing to the search for appropriate adaptation solutions.
- Highlight how optimal adaptation solutions must take into account the respect for cultural heritage, its associated values, human dimension, and identity, to prevent adaptation solutions from deviating into maladaptation. The direct involvement of local communities or their stakeholders becomes fundamental in proposing useful adaptation solutions and maximizing their acceptance.

2.5.3 Lessons Learned

Key takeaways

- Importance of cultural heritage as an “activation” tool for climate change adaptation, to maximize acceptance and avoid maladaptation.
- Importance of including cultural heritage in future preservation measures.
- Importance of considering future climate in the decision-making process for the conservation of the tangible heritage.

Challenges encountered

- Participatory activities or conducting engagement activities such as interviews are very time-consuming and resource-intensive. It is therefore necessary to plan such activities well in advance, taking into account potential unforeseen circumstances.
- Available resources should be considered in relation to the objectives set, and consequently, the choice of a possible research approach to adopt.
- Access to data of private buildings is difficult. Only social housing companies were available to provide the data needed, although with significant delays. It is necessary to take this time into account in the planning phase. While it shows the lack of awareness of private owners and single citizens, it also shows an increasing interest from the public sector on developing strategies for the long-term management of the built environment.



Future recommendations

- Grasping the implications and the meaning of "cultural heritage" to comply with the guidelines of the main legal instruments on the matter.
- It is crucial to actively involve stakeholders or representatives of local communities to understand their perspectives, gather potential solutions, and explore potential unexplored path.
- Not all adaptation solutions may be optimal. It is therefore essential to have a clear objective of selecting solutions that are respectful of local communities, the environment, and cultural heritage.
- Research on cultural heritage that actively engages local stakeholders enables the development of context-specific solutions, addressing potential challenges in applying solutions from other regions.

Barriers to transferability

- Solutions devised for a specific demo-site may not be universally applicable to other regions with differing territorial or climatic conditions. Consequently, a methodology emphasizing the direct engagement of local stakeholders in developing diverse adaptation solutions is essential. Cultural heritage is pivotal in this context.
- In the case of energy and hygrothermal simulations, the approach can be transferred to other regions, but the results cannot be simply generalized. The replication in other areas, climates and building typologies would require further simulation.

2.5.4 Conclusion

The task emphasizes the value of **cultural heritage** as a key resource in developing **climate adaptation solutions**, particularly in sectors like **viticulture and building renovation**. By combining **traditional knowledge** with **innovative practices** and involving **local stakeholders** as custodians of heritage, solutions become more **sustainable, context-sensitive, and transferable**. In viticulture, experienced professionals help bridge past and future practices to address emerging climate challenges. In the built environment, **dynamic simulations under future climate scenarios** reveal the continued importance of winter insulation and the rising need for **summer cooling strategies**, with findings showing that some concerns, like the supposed downsides of internal insulation, are overstated. Ultimately, the task underscores the need for **participatory approaches** that prioritize **dialogue, local engagement, and community well-being**, ensuring that adaptation strategies are both effective and respectful of cultural and environmental values.

2.6 Pursuing behavioural change for climate resilient tourism (Task 4.22)

Today, climate variability and change affect various economic sectors. **Tourism**, in particular, **is a widely recognized climate-sensitive sector** involving diverse leisure activities around the globe, such as sun-sea-sand, cultural experiences, cycling, golf, skiing, hiking and sailing. Climate variability and change influence source markets and tourist behaviours (including travel motivations and destination choices), tourism operators (such as accommodations, infrastructure design, and transport), and the destinations themselves (Scott et al., 2010).

The tourism industry is also expected to suffer from the **indirect impacts** of climate change, such as reduced water availability and quality, increased food costs, higher energy prices, rising sea levels, beach erosion, and more frequent wildfires (Scott, 2010; Gössling et al., 2012; Scott et al., 2012, 2019). Tourists **water use** is especially relevant (Gössling et al. 2012; Hadjikakou et al., 2013; Becken, 2014) and the water demand is expected to grow with the increase in the number of tourists, hotels and tourist attractions – e.g., spas, pools and golf courses (Gössling & Peeters, 2015).

The Mediterranean region is one of the areas most affected by the impacts of climate change (IPCC, 2022). In this line, Spain will have to face the challenges imposed by climate change through mitigation and adaptation strategies at local and regional scales for the tourist industry, which is the most important economic sector in terms of income revenues and workers employed. According to the UNWTO highlights (UNWTO, 2018), Spain became the world's second-largest destination in 2017 with 81.8 million international tourist arrivals and 68 \$US billion tourist receipts (i.e. total expenditure by international visitors in the destination country). Moreover, it was the leading European country in numbers of foreign visitors of overnight stays. Climate change will likely degrade the present favourable conditions for outdoors tourist activities during the Mediterranean summer by 2050, while climatic conditions are expected to improve during spring and autumn (Rutty & Scott, 2010; Amengual et al., 2014).



The present research evaluates **stakeholders perception regarding sustainability in the tourist sector on the Catalan coast**, Spain. We consider that engaging tourist stakeholders is of great importance to pursue behavioural change for resilient tourism (Boqué-Ciurana et al., 2024). The tourism destination should, in accordance with its natural resources, identify what authentic and unique experiences it can offer to the modern tourist. Identifying (and later implementing) unique and innovative experiences, which can be reasonably and successfully marketed to the appropriate target audience, should be one of the main priorities of tourism destination marketing. In that sense, destinations are increasingly aware of the need to develop **innovative yet sustainable experiences** that support all three pillars of sustainable development: economic, environmental, and social (Purvis et al., 2019). It is important to develop and enhance sustainable experiences that derive from the natural characteristics of the destination (Haid et al., 2021) and are supported and co-created by all stakeholders in the destination (Font et al., 2021) and are also demanded by environmentally conscious tourists (Fadda et al., 2019). In this line, well-informed management should include local communities, waste, infrastructure, traffic, and environmental management and prevent intergroup conflicts to ensure sustainable and environmentally friendly development (Machado et al., 2018; Fredline et al., 2005; Machado et al., 2021; Tse et al., 2022). For this reason, the project partners adapt the methodology for **co-creating climate services for tourism** (Font et al., 2021) to explore the perceptions of the local stakeholders impacted by climate variability and change in a specific tourist area in southern Catalonia. **Behavioural change** plays a crucial role in addressing climate change in coastal tourist destinations. Recognizing the impact of individual actions on the environment, tourists and local communities can adopt sustainable behaviours that minimize their carbon footprint. This includes practicing responsible waste management, conserving water resources, choosing eco-friendly transportation options, and supporting local businesses that prioritize environmental sustainability. By fostering a collective shift in behaviour towards more climate-conscious practices, coastal tourist destinations can contribute to mitigating climate change, preserving fragile ecosystems, and ensuring the long-term viability of tourism industry in these areas.

Skeiseid, et al (2020) explored how **communication** to motivate sustainable change in tourism behaviour should be made. The results indicate that softer, less assertive messages are more effective in influencing individuals to change their behaviour. Practical implications suggest that tourism marketers and policymakers should use softer, value-consistent messaging to promote sustainable tourism, emphasizing normative and biospheric values to encourage behavioural change.

Dillimono & Dickson (2015) examined how tourists in lesser-developed countries, particularly Nigeria, understand climate change. They find that many Nigerians have limited awareness of climate change and do not connect their travel habits with its impacts. Dillimono & Dickson (2015) emphasized that there is a need for further research to find **solutions that go beyond individual behaviour change**.

Seekamp et al., (2019) discussed how climate change can affect tourism in vulnerable coastal areas, like the Outer Banks in North Carolina, USA. Their study suggests that tourism planners need to find new ways to support infrastructure and preserve beaches. It also emphasizes the importance of educating tourists about climate change adaptation efforts.

For this reason, the present task aims to explore what behavioural change is needed among the stakeholders for **climate resilient tourism** in the Catalan coast. Project partners engage local stakeholders to identify their perception regarding tourism and the following concepts: climate and weather, water and energy consumption and management, and beach dune systems.

In studying behavioural change for climate-resilient tourism, the gap to address often centres around the **disconnect between awareness of climate challenges and actionable responses** within the tourism industry. Specifically, the following key areas were targeted:

- **Awareness-action gap:** while stakeholders may recognize the importance of climate resilience, there is often limited understanding of how to translate this awareness into practical, behaviour-based solutions.
- **Stakeholder engagement:** tourism destinations frequently lack inclusive mechanism to involve diverse stakeholders such as local communities, business operators, and tourists – in co-developing climate resilience strategies.
- **Behavioural barriers:** existing sustainability measures often fail due to ingrained behaviours, resistance to change, or misaligned incentives within the tourism sector. Understanding psychological and economic drivers is crucial to overcoming these barriers.
- **Sectoral integration:** tourism resilience efforts often remain siloed, neglecting the broader context of ecosystem sustainability, water use, energy efficiency, or collaboration across sectors.

By addressing these gaps, the task seeks to advance practical approaches that motivate and sustain behavioural change among stakeholders, fostering a **more adaptive and resilient tourism model**. This, in turn, helps destinations better prepare for and respond to the challenges posed by climate variability and change.



The solution involves a **co-creation process** with stakeholders to integrate climate-resilient tourism principles into three critical areas: climate potential indicators, resource use perceptions (water and energy), and awareness of beach-dune systems. The goal is to foster a shared understanding and actionable strategies that align sustainability with the tourism sector's needs.

Task objectives are the following:

1. **Co-create climate potential indicators**
 - a. Objective: identify metrics that highlight tourism activities compatible with seasonal climate characteristics while considering resilience and adaptability.
 - b. Activities:
 - i. Conduct workshops with stakeholders to define criteria for climate potential.
 - ii. Use participatory approaches to identify key climate variables.
 - iii. Develop a scoring framework for assessing climate potential for diverse activities.
2. **Evaluate perceptions about water and energy use in tourism**
 - a. Objective: understand stakeholder awareness, concerns, and attitudes regarding the consumption of water and energy in tourism facilities and practices.
 - b. Activities:
 - i. Design and conduct co-creation workshops.
 - ii. Explore priority and viability willingness to adopt measures like water-saving devices, renewable energy.
3. **Assess the importance of beach-dune systems**
 - a. Objective: gauge the level of understanding and support among stakeholders regarding the role of beach-dune systems in coastal resilience.
 - b. Activities:
 - i. Organize participatory workshops to assess knowledge about beach-dune systems.
 - ii. Develop visual tools to raise awareness of their role in mitigating climate impacts.
 - iii. Identify barriers to protecting and restoring beach-dune ecosystems in the context of tourism development.

This **integrated approach** equips tourism stakeholders with actionable insights and collaboratively developed tools for advancing climate resilience in the sector.

2.6.1 Results

Task outcomes

- A set of co-created climate potential indicators tailored to local tourism contexts.
- Insights into stakeholder perceptions of water and energy use to inform targeted sustainability interventions.
- Increased awareness of the ecological and protective value of beach-dune systems, fostering support for conservation initiatives.

Methodology

The methodology for this task integrates a co-creation process and data analysis to develop climate potential indicators and assess perceptions regarding water, energy, and beach-dune systems in tourism. This approach is adapted from the co-creation methodology defined by Font et al., (2021), emphasizing mind maps and consensus-building to engage stakeholders effectively.

1. **Co-creation process:** the co-creation methodology provides the backbone of stakeholder engagement and the development of actionable outputs.
 - a. Adopted framework: the approach defined by Font et al., (2021) combines participatory mind mapping to explore ideas and consensus-driven decision-making to identify priorities and solutions.
 - b. Stakeholder engagement: workshops involved representatives from the tourism industry, local municipalities, conservation organizations, and academic experts, stakeholders collaboratively:
 - iv. Identified relevant variables and thresholds for climate potential indicators.
 - v. Discussed perceptions of water and energy use, including current challenges and future opportunities.
 - vi. Explored the ecological, cultural, and protective importance of beach-dune systems.
2. **Data collection from workshops:**
 - a. Mind maps organize brainstorming sessions and visualize the relationships between variables.
 - b. Iterative consensus refines initial insights into measurable, actionable indicators and interventions.



3. **Development of climate potential indicators:** to compute climate potential indicators for tourism activities, we combine diverse datasets and models:
 - a. Climate model data: historical climate data serves as the foundation.
 - b. Meteorological and oceanographic data: the SIMAR model from Puertos del Estado provides met-ocean data to assess coastal resilience and suitability for marine and coastal activities.
 - c. Tourist data: visitor preferences and behaviours are derived from Eurecat data, providing critical insights into seasonal demand.

This methodology provides a structured and collaborative approach to develop actionable strategies and tools for climate-resilient tourism, ensuring scientific rigor and stakeholder relevance.

Collaborations

The collaboration in this project involved a variety of **stakeholders from the Costa Daurada and Terres de l'Ebre regions**, including local governments, tourism boards, environmental agencies, and private companies. Participants shared perspectives on climate change adaptation, focusing on sustainable tourism and its resilience. Public institutions, such as the Tarragona Water Consortium and the Meteorological Service of Catalonia, provided crucial information, knowledge, and insights on climate conditions and water resource management. Private entities like Cambrils Club Natació and Deltacleta S.L. contributed expertise from recreational and water-based tourism. The collaboration aimed to create integrated solutions for a more climate-resilient tourism model.

Publications and outreach

Several oral presentations and posters have been presented in international conferences, also presented in outreach events:

- Boqué-Ciurana, A., Céster Lozano, I., Vasileiou, A., Dermitzakis, E., Nikoloudis, C., Aguilar, A., (April, 2025). Developing a Climate Resilience Tool for Coastal Tourism: Local Adaptation on the Catalan Coast. In EGU General Assembly. <https://doi.org/10.5194/egusphere-egu25-9114>.
- Boqué-Ciurana, A., Saladié, Ò., Garcia-Lozano, C., Borràs, G., Martí, C., Soto, M. T. R., ... & Cester, I. (2024). Driving Change: User Engagement and Governance in Climate Adaptation for Coastal Destinations (No. EMS2024-523). Copernicus Meetings.
- Boqué-Ciurana, A., Saladié, Ó., Garcia-Lozano, C., Borràs, G., Giné, G., Labairu, I., ... & Aguilar, E. (2024, April). Climate Services and Behavioral Change: Enhancing Resilience in Mediterranean Tourism through co-creation. In EGU General Assembly Conference Abstracts (p. 8456).
- (2025, January) What do hotels in Costa Daurada (Catalonia) claim to be doing regarding climate change and sustainability? An analysis based on the content available on their websites. In XIII Congreso Internacional de la Asociación Española de Climatología (AEC).
- Boqué-Ciurana, A., García-Lozano, C., Martí, C., Borràs, G., Aguilar, E., Labairu, I., Giné, G., (2025, January) Proposal for behavioral change for climate resilient tourism: Costa Daurada and Terres de l'Ebre. In XIII Congreso Internacional de la Asociación Española de Climatología (AEC).
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- Mention to Impetus project task 4.22 in the training named co-creation of climate indicators for the Argentinian northeast (18/03/2024- 22/03/2024).
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2.6.2 Impact

- **Climate-resilient tourism strategies:** The project successfully contributed to developing actionable strategies for promoting climate-resilient tourism. By integrating local knowledge, climate data, and sector-specific expertise, the project enhanced the capacity of tourism stakeholders in the Costa Daurada and Terres de l'Ebre regions to address climate change challenges.
- **Scientific rigor and stakeholder relevance:** Collaboration with public institutions, like the Tarragona Water Consortium and the Meteorological Service of Catalonia, ensured the scientific rigor and relevance of the project, particularly in addressing water resource management and



climate conditions. Private stakeholders added a practical tourism perspective, resulting in strategies that are both scientifically sound and practically viable.

- **KPIs and evaluation:** The project met its task objectives by delivering a collaborative framework that engaged both public and private stakeholders. Short-term effects include increased awareness and co-creation of climate-resilient tourism strategies. Long-term effects focus on the region's increased ability to adapt to climate change and the institutionalization of new processes for climate adaptation. The project is aligned with the KPIs specified in D4.1, highlighting a positive impact on local stakeholders' capacity for adaptation and enhanced knowledge sharing.
- **Advancing project goals:** The collaboration and co-creation process have been essential in advancing the goals of the project and its work packages, contributing directly to enhancing local tourism resilience to climate change. The task provided both concrete results (climate-resilient strategies) and theoretical insights (sustainable tourism and behavioural change) which were communicated through publications and outreach events.
- **Scalability and adaptability:** The results of this project can be tailored to other regions with similar climate risks or tourism characteristics. However, transferability may face limitations in areas with differing governance structures, climates, or tourism models. Adapting the approach requires region-specific adaptation strategies and the involvement of local stakeholders to ensure the effectiveness and relevance of the findings.
- **Best practices and limitations:** The collaborative co-creation process demonstrated its effectiveness, particularly in regions with strong local governance and engagement. However, in areas with less climate awareness or weaker institutional structures, adapting this approach may require additional support for local capacity building. Best practices include prioritizing stakeholder engagement, ensuring long-term commitment, and applying a tailored approach based on local conditions.

2.6.3 Lessons Learned

Key takeaways: collaboration between government, tourism and climate agencies is key for building climate resilient tourism. Local expertise and climate data integration are vital for addressing risks and ensuring sustainability.

Challenges encountered: coordinating diverse stakeholders caused delays, and aligning data availability with timelines was challenging.

Future recommendations: training on climate resilience should be prioritized to ensure uniform understanding in the tourist sector.

Barriers to transferability: the approach may not transfer easily to regions with different climate risks, governance structures, or tourism models. Local adaptation strategies, through co-creation, are necessary to cater to each region's unique conditions.

2.6.4 Conclusion

In conclusion, this project has highlighted the importance of **cross-discipline collaboration** in addressing climate risks in tourism. Integrating local and climate knowledge through a **co-creation process** enabled the development of more tailored and effective solutions. The flexible approach is key to the success of future projects in regions with specific conditions.

2.7 Improving integrated climate risk assessment and management through innovative participatory approaches (Task 4.23)

Policymakers increasingly require evidence-based climate action plans and adaptation strategies to address the advancing impacts of climate change. **Climate Risk Assessments (CRAs)** are an essential step at the basis of adaptation planning, focusing on current climate extremes, future scenarios, and how various factors (e.g., ecosystem, technical, socio-economic) influence risks across sectors. These assessments evaluate potential impacts and risks linked to climate change and extremes. Such assessments integrate diverse data and methods to evaluate how climate hazards interact with exposure and vulnerability. However, no standard CRA methodology exists. For instance, in Europe, national CRAs typically follow a similar sequence but lack a unified approach. An EEA report (2018) provides insights into these practices.

To address the need for standardized frameworks, Eurac Research and partners developed the **climate impact chain framework**. Initially applied in the European Alps, it later informed Germany's national climate risk studies and GIZ guidelines (Fritzsche et al., 2014; Zebisch et al. 2017; Zebisch et al. 2023). This framework, referenced in ISO 14091 (ISO/IEC, 2021), has since been used in nearly 20 national



CRA globally (e.g., Burundi, Bangladesh, Thailand), gaining prominence for its suitability in adaptation planning.

The Impact Chains (ICs) conceptualize risk as the **interplay between hazard, exposure, and vulnerability**, allowing for detailed, context-specific assessments. Impact chains align with the IPCC's AR5 and AR6 climate risk concept (IPCC, 2022), emphasizing the interaction of hazards, exposure, and vulnerability. This assessment help to **prioritize adaptation actions** by addressing the most influential vulnerability drivers and exposure elements. Impact chains are both graphical and participatory. They allow for a **visual representation** of cascading impacts triggered by climate-related hazards, highlighting the entry points for climate change adaptation. Each impact chain typically begins with a specific hazard, traces its effects through intermediate impacts, and links these to exposed elements and vulnerability factors. This structure enables a more transparent and shared understanding of risks and fosters collaborative identification of adaptation options. The approach is typically implemented through **stakeholder workshops**, desk-based research, and where relevant, interviews.

Figure 13 shows the basic structure of an impact chain and its components. Definitions of key terms are summarized in Table 3.

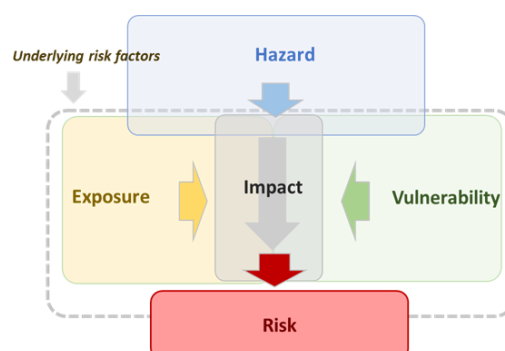


Figure 13: The risk components and the basic structure of the impact chain. Source: Eurac

Table 3: Main definitions of the components of risk used within the impact chains. Source: Pittore et al. 2025

Risk	Combined impacts, exposure elements and vulnerabilities that describe potential risks highly relevant in the scope of the impact chain.
Hazard	Climatic influence, climatic or non-climatic event or trend that may constitute a hazard to the exposed assets and systems and result in an impact and possibly a risk (with damage or loss).
Exposure	The (presence of) people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2022).
Vulnerability	Vulnerability refers to the predisposition/propensity of exposed elements such as human beings, their livelihoods, and assets to be adversely affected by a natural hazard. This element contributes to and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and/or lack of capacity to prevent, prepare, respond, cope and/or adapt (IPCC, 2022).
Impacts	Effect or consequence caused by a hazard or another impact. Within the impact chain, Impacts relate to adverse (negative) consequences that can be considered as potential materializations of risks.

Goals within IMPETUS

Within the IMPETUS project, the development and application of impact chains aim to support climate risk assessment in key sectors and contribute to broader decision-support efforts. The work focused on the **agriculture and built environment sectors** in the Mountain demo site of Valle dei Laghi, providing a structured basis for understanding climate risks and informing other project tasks. A key goal was to develop standardised impact chains using the KUMU platform, contributing to a growing online library

of impact chains that are publicly accessible and supported by detailed sector-specific documentation. Furthermore, the **approach was replicated in the Carpathian region** to test its transferability within the mountain bio-geographical region. Finally, the work also aimed to advance the **development of guidelines** for the standardised creation of impact chains, promoting consistency and reusability in climate risk assessments across regions and sectors.

2.7.1 Results

Application of the IC approach in Valle dei Laghi

On May 24th, 2023, two participatory workshops were held in Valle dei Laghi to co-develop impact chains for the agriculture and built environment sectors in the context of climate change. The overarching goal of these workshops was to identify, together with local stakeholders, the main climate-related risks affecting these sectors, using a structured, evidence-based approach.

The workshops applied the impact chain methodology developed by Eurac Research, which allows for a graphical and intuitive representation of the cascade of impacts triggered by climate events. By tracing links between climatic hazards, cascading impacts, and the vulnerability and exposure of affected systems, the method helps to **identify potential leverage points for adaptation and areas in need of risk management improvement**. Beyond physical and environmental factors, the approach also integrates social and institutional dimensions, such as adaptive capacity and governance challenges.



Figure 14: One of the workshops organised in Trento to co-develop impact chains with the stakeholders of the Valle dei Laghi demo site.

Overall, **11 stakeholders** joined the agriculture workshop. Participants included researchers, representatives from agricultural associations and insurance companies, as well as provincial managers and officials. **13 stakeholders** took part to the built environment workshop, including participants from the academic system, public administration, and civil society. Researchers contributed scientific input, while provincial managers and officials brought policy and planning perspectives. Firefighter chiefs added practical experience from the field, enriching the discussion on climate risks and responses. This diverse mix ensured a comprehensive discussion that integrated scientific knowledge, practical experience, and policy perspectives.

In the agricultural sector workshop, participants highlighted two main clusters of impacts:

- **Water scarcity** and resulting competition among sectors for limited water resources.
- **Decline in grape and wine quality and quantity**, for example due to a decrease in acidity, leading to economic losses for local producers.

For the built environment workshop, the impact chains focused on:

- **Physical damage to buildings** (e.g. roofs, façades, windows) and **increased indoor discomfort** due to extreme weather events.
- Challenges related to **water availability**, including both scarcity (e.g. for drinking water) and excess (e.g. pluvial flooding and overloaded drainage systems).

The findings from these workshops not only provide a localised risk picture for Valle dei Laghi, but also contribute to broader assessments relevant for adaptation planning in the Province of Trento.

Interviews conducted as part of the Task 4.21 on activation of cultural heritage helped to integrate and validate the workshop outcomes for the agricultural impact chain, while also surfacing additional vulnerability factors that are critical for a comprehensive climate risk assessment. Several **structural and institutional vulnerabilities** emerged, such as insufficient data and monitoring systems, and a lack of drought and hail warning systems, which limit farmers' ability to prepare for and respond to extreme weather events. Low awareness of water reuse and saving practices, combined with weak enforcement of withdrawal regulations, further increases exposure to water scarcity risks.

From a **socio-economic perspective**, the interviews revealed a high economic dependence on viticulture, with limited diversification into other crops or income sources. This creates significant risk in the face of climate-induced changes in grape yield and quality. Moreover, financial constraints and poor insurance coverage make it difficult for smallholders to absorb climate-related losses or invest in adaptive measures. **Technical and governance challenges** were also highlighted, including limited access to technical assistance, weak coordination across governance levels, and difficulties in switching to grape varieties with greater climate or pathogen resistance. These factors reduce the sector's overall adaptive capacity and slow the uptake of more resilient farming approaches. Together, these findings provide a more nuanced picture of vulnerability in the agricultural sector and strengthen the foundation for identifying targeted and culturally sensitive adaptation options.

The final **impact chains for Valle dei Laghi** are illustrated below and can also be explored interactively on Kumu (<https://kumu.io/impetus/impetus-impactchains-ds7#agriculture-valle-dei-laghi>). Kumu is an online tool which enables the structured creation and consultation of impact chains. The impact chain on the agricultural sector is presented below.

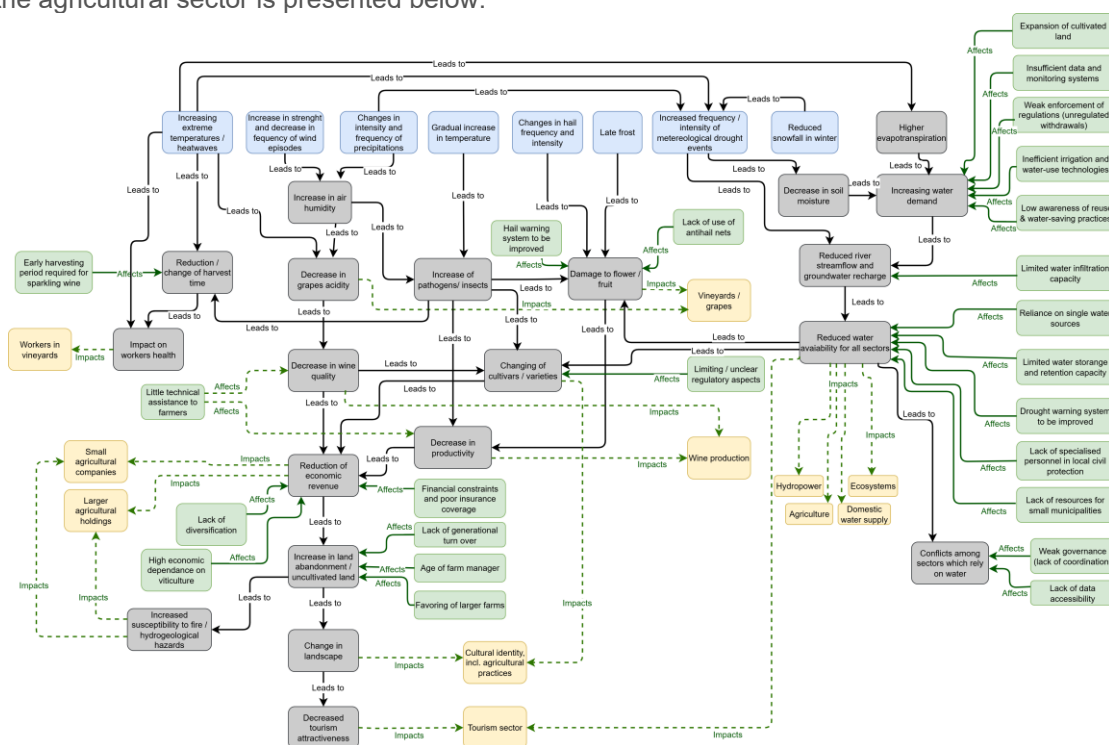


Figure 15: Impact chain on agriculture in Valle dei Laghi resulting from the workshop with local stakeholders in Trento, integrated by the cultural heritage interviews.

Replication of the IC approach in the Carpathians

The main objective of the workshop was to replicate and transfer the impact chain approach, originally applied in Valle dei Laghi demo site, to a comparable context **within the mountain biogeographical region**. Given the strategic importance of this region in Europe, there was strong interest in extending the climate risk analysis for the agricultural sector to other mountainous areas. The workshop was made possible through the collaboration of local and international experts (Mountain Research Initiative, Carpathians Convention) who provided funding and connections to their international networks. Following the recommendation of the Carpathian Convention Secretariat, the White Carpathians and specifically the **Zlín region in the Czech Republic** were selected as a suitable replication site due to their similarities with the Italian demonstration area, including the presence of apple orchards, vineyards, and a predominantly rural landscape with small villages. Hostětín was chosen as the venue for its accessibility and the support offered by the local partner, the Veronica Centre, which contributed through its established stakeholder network and capacity to provide moderation in the local language. As in Valle dei Laghi, the practical aim of the workshop was to **identify key climate-related risks for agriculture through a participatory approach**. In total, **16 participants** attended the event, bringing together a mix of researchers, environmental educators, and the head of the hosting centre, alongside a translator, the director of a local agricultural company, and independent consultants. Regional managers and officials also participated, ensuring a balance between scientific, educational, practical, and policy-

oriented perspectives. Moreover, two international participants took part to the workshop to further expand the outreach and knowledge transfer. The main climate-related risk identified during the workshop was the **reduction in both the quality and quantity of crop yields and agricultural products**, particularly in orchards and pastures. The resulting impact chain is presented below.

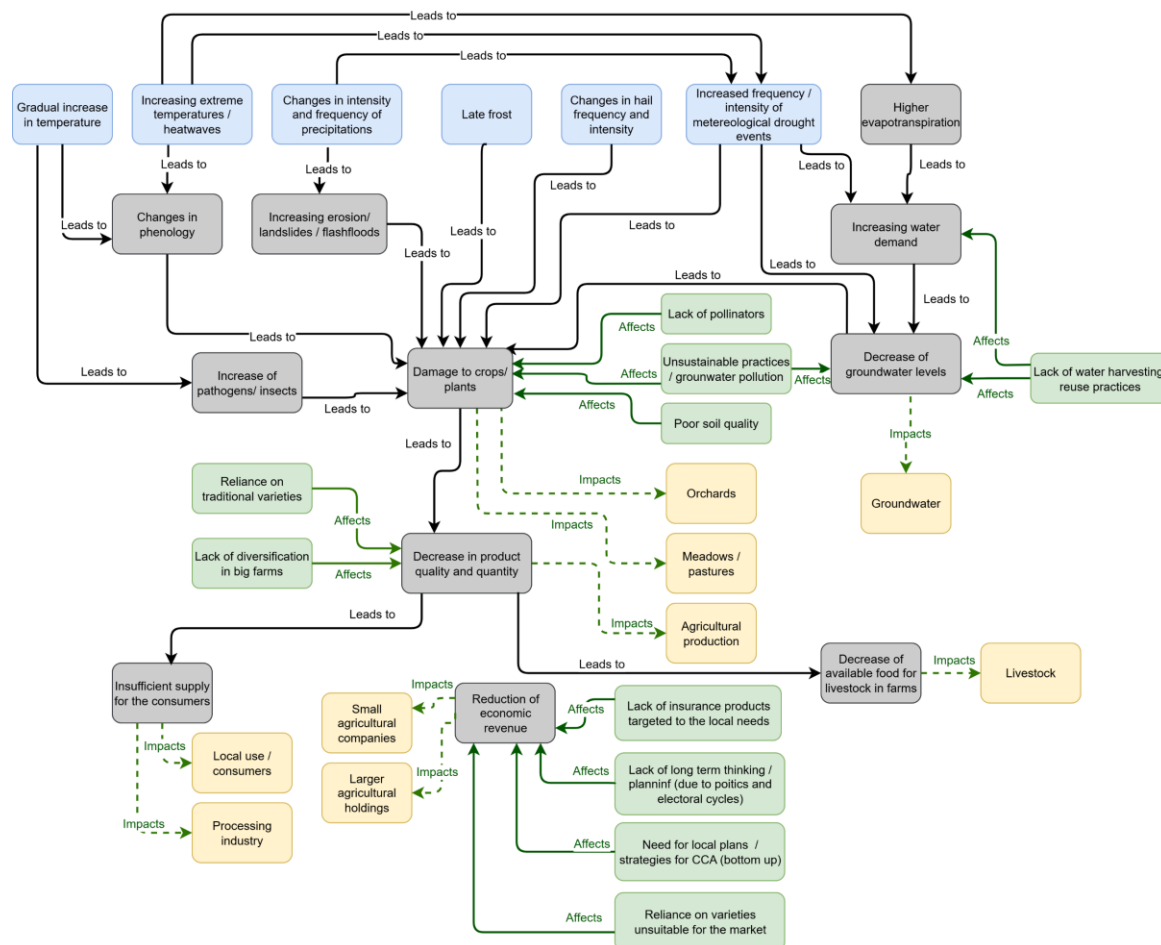


Figure 16: Impact chain on agriculture resulting from the replication workshop held in Hostětín focussing on the Zlín region in Czech Republic.

The impact chains developed for Valle dei Laghi and the Zlín region share a common core structure. Both focus on the agricultural system and identify **rising temperatures, shifting precipitation patterns, hail, and frost** as the main climate-related hazards. They also converge on impacts like **reduced crop quality and yields, increased pests and diseases, economic losses, and water scarcity**. However, in Valle dei Laghi, water scarcity emerged as a dominant issue, with agriculture, hydropower, and tourism competing for diminishing water resources. Participants emphasized rapid shifts in hydrological cycles and tensions between irrigation, domestic supply, and energy production. This focus was less prominent in the Hostětín's IC, where local food security and livestock concerns were more central. Additionally, Valle dei Laghi's IC reflects region-specific vulnerabilities tied to viticulture practices, such as reduction in grape acidity, early harvesting needs, reliance on single water sources, and demographic challenges in farm management. In contrast, Hostětín's IC emphasizes systemic issues like soil degradation, groundwater pollution, and the need for bottom-up climate adaptation planning.

2.7.2 Impact

Evaluation of results and task objectives

- The task successfully achieved its objectives by applying and replicating the impact chain methodology to assess climate-related risks in agriculture and the built environment within mountain regions. Moreover, the approach was adopted by WP5 and applied across all

demonstration sites in the IMPETUS project. In the short term, this approach enhanced local awareness and understanding of climate risks through participatory workshops, strengthening stakeholder engagement across sectors.

- The transfer of methodological knowledge was fostered via training sessions, a MOOC lesson, and the development of guidelines for structured application of the impact chain approach.
- Direct outcomes included the identification of concrete vulnerabilities and adaptation entry points in each demonstration site.
- Over the longer term, the task contributed to building local capacities for climate risk assessment and adaptation planning, increased the potential for institutional adoption of participatory risk governance approaches. Indirectly, it reinforced partnerships among local institutions, researchers, and civil society, supporting broader capacity-building efforts at regional and transnational scales.
- Overall, the use of ICs advanced Sustainable Development Goal 13 on Climate Action by strengthening resilience and adaptive capacity to climate hazards (target 13.1) and improving education, awareness, and institutional capacity on climate change mitigation and adaptation (target 13.3).

Transferability and adaptability

- Within the project, impact chains were applied in WP5, where they served as a tool for structuring the analysis of climate-related risks and were instrumental in guiding the co-development of adaptation pathways in each demo site. By mapping the causal links between hazards, exposure, and vulnerability, they helped identify criticalities and design context-specific adaptation options.
- Their flexible structure allows applications at varying levels of detail and across different contexts. The replication of the approach in the White Carpathians demonstrated the method's transferability and effectiveness in engaging stakeholders, fostering mutual learning, and raising awareness of climate change adaptation.
- The approach can be adapted to different thematic areas, such as agriculture or the built environment, and applied in a range of socio-ecological contexts based on available data and local stakeholder priorities.
- Best practices for replication include collaborating with trusted local partners, tailoring facilitation and communication to the local language and context, and maintaining flexibility in the design of participatory processes to reflect regional needs and capacities.

Performance against KPIs

- **Number of workshops, focus groups and training activities performed:** 3 participatory workshops were successfully carried out, two in the Valle dei Laghi (Italy) and one in the White Carpathians (Czech Republic), involving a broad mix of stakeholders from public administration, research, civil protection, agriculture, and civil society. Moreover, two international participants joined the workshop in the Czech Republic to further expand outreach and knowledge transfer. One of the lessons of the Massive Open Online Course (MOOC) focused on Impact Chains, further strengthening training and dissemination efforts. In addition, guidelines (Pittore et al., 2025) are being developed to support replication and facilitate structured implementation of the approach in other contexts.
- **Number of impact chains developed:** A total of 4 impact chains were developed during the project. Two focused on the agricultural sector: one for the Valle dei Laghi, enriched with insights from semi-structured interviews on intangible cultural heritage, and one for the Zlín Region in the White Carpathians, reflecting the area's specific hazard, exposure, and vulnerability dynamics. An additional impact chain was created for the built environment in the Valle dei Laghi. Finally, a dedicated IC on water scarcity was developed to support the selection of adaptation options and the co-development of adaptation pathways in WP5.
- **Number of identified strengths/weaknesses in risk management practices:** The impact chain methodology and participatory discussions enabled the identification of several key vulnerabilities in risk management practices. Notable weaknesses included limited insurance coverage, insufficient water retention and storage systems, fragmented governance and coordination, lack of technical assistance, and poor enforcement of water withdrawal regulations. These insights informed the choice of adaptation options for the development of adaptation pathways.

2.7.3 Lessons Learned

Key takeaways



- The impact chain approach proved to be an effective and adaptable tool for visualising and understanding complex climate risk dynamics, especially when applied through participatory, multi-stakeholder workshops.
- It enabled the integration of local knowledge, scientific evidence, and institutional insights, facilitating the co-production of context-specific risk narratives.
- Embedding cultural and intangible heritage insights (via interviews) enriched the understanding of vulnerabilities, particularly for agriculture, highlighting the importance of traditional practices and socio-demographic shifts.
- The successful replication of the approach in the Carpathians demonstrated its scalability and potential for broader application in the mountain biogeographical region and beyond.
- The method not only supports risk assessment, but also informs the development of adaptation pathways, reinforcing its value as a tool for climate adaptation planning.

Challenges encountered

- Stakeholder selection may introduce bias, with certain vulnerabilities or perspectives underrepresented. This was addressed by complementing workshop inputs with semi-structured interviews and desk-based research.
- Language barriers emerged during the replication workshop in the Czech Republic. These were mitigated through bilingual moderation and group division, ensuring inclusivity without compromising depth of discussion.
- Time constraints and stakeholder fatigue limited the possibility of iterative refinement of the impact chains through multiple stakeholder engagements.
- Aligning the approach with other project components (e.g., adaptation pathways, indicators) required continuous coordination across work packages, which can prove to be resource intensive.

Future recommendations

- Ensure diverse and inclusive stakeholder representation, including marginalized voices and cross-sectoral actors, to capture a wider range of vulnerabilities and capacities.
- Ensure sufficient time and resources are allocated for stakeholder engagement, including preparatory communication and post-workshop follow-up, to deepen local ownership of results. In particular, build in time for iterative feedback loops, allowing stakeholders to validate and refine impact chains in subsequent sessions.
- Where possible, provide localized training or capacity building before workshops to ensure participants are familiar with key concepts and methods. When working in a different language context, ensure bilingual co-facilitation or interpretation to ensure inclusive participation and better understanding.
- Foster stronger connections between risk assessment and decision-support tools, for example by aligning impact chains more explicitly with adaptation pathway planning from the start.
- Encourage the use of adaptation pathways and decision-support tools to build on the outcomes of impact chains and link risk assessment to long-term planning.
- Expand and maintain a public library of impact chains, supported by clear documentation and guidance, to foster broader reuse, learning, and comparison across contexts.

Barriers to transferability

- While the impact chain approach is context-sensitive, the successful replication in the Carpathians shows that, with proper facilitation and local engagement, it is highly adaptable across different mountain regions. However, this flexibility can lead to variations in quality and comparability without adequate training and documentation.
- Some risk concepts (e.g., vulnerability, exposure, adaptive capacity) can be abstract and difficult to grasp, especially when working across different cultural and linguistic contexts. Misunderstandings may arise when key terms lack clear equivalents in local languages.
- Successful application requires moderation and facilitation expertise, which may not always be available locally without training.
- The method relies heavily on participatory processes; in contexts with limited civic engagement or trust in institutions, stakeholder involvement may be challenging.

2.7.4 Conclusion

This task **successfully applied and replicated the impact chain methodology** to assess climate-related risks in **agriculture and the built environment** in mountain areas. In Valle dei Laghi, two



detailed chains were co-developed with stakeholders and further enriched through interviews on cultural heritage and farming practices. In the Carpathians, the approach was effectively transferred and adapted to a new regional context. The process helped identify key **climate hazards** and their **cascading impacts**, while also highlighting critical **vulnerability factors** and **adaptation options**. The visual and participatory nature of the method enhanced stakeholder engagement and supported the development of adaptation pathways (WP5). Overall, the impact chain approach proved to be **flexible and scalable**, offering a structured tool for climate risk assessment and adaptation planning that can be replicated in diverse settings with appropriate facilitation and local engagement.

2.8 Establishment of a Climate Change Adaptation Plan governing climate risk management (Task 4.24)

Changes in climatic conditions identified in Latvia are related to steady rise in air temperature, increase in total atmospheric precipitation and increase number of days with heavy and very heavy precipitation. It has been assessed that weather conditions not characteristic to and extreme for Latvia will be a more frequent reality in the future causing damage to society, business, infrastructure and environment (Ministry of Environmental Protection and Regional Development, 2019). It is strongly recommendable that **measures for Climate Change Adaptation (CCA) must be implemented at all levels** – at local, regional and national level. The Ministry of Climate and Energy coordinates the implementation of climate change adaptation policies and measures. There are 5 planning regions operating in Latvia: Riga, Zemgale, Kurzeme, Vidzeme, and Latgale.

IMPETUS demo site Zemgale Planning Region (ZPR) comprises five regional municipalities (local governments) – Jelgava, Aizkraukle, Bauska, Dobele, Jekabpils, and Jelgava State City municipality. National climate targets are binding for regions and municipalities within the scope of their planning competence. The **draft Law on Climate**¹ prescribes that regional plans shall include CCA goals, priorities and conditions planned for their achievement in the sustainable development strategies and development programs, as well as define actions and measures to achieve these goals. Local government should include CCA objectives, priorities, activities and investment projects in its sustainable development strategy, development programme or other territorial development planning documents in accordance with the objectives, priorities and conditions set for the planning region. Climate change related aspects have been highlighted in several policy documents elaborated for Zemgale planning region within the period of 2010–2020. The focus of these documents has been mainly on climate change mitigation aspects in relation to production and utilisation of renewable energy and increase of energy efficiency at various sectors. CCA has been identified as one of the priority areas of action in **Zemgale Planning Region Development Program 2021–2027**, so far, no comprehensive CCA plan for the region has been developed.

To increase the resilience of the region towards the climate change, a **Zemgale Regional Climate Change Adaptation Plan** has been elaborated within the IMPETUS project. Objective is to apply tailored participatory planning approaches for stakeholder involvement from public, private, and civic sectors to develop a **shared vision and measures** for the climate change adaptation considering cross-sectoral (e.g., agriculture, forestry, infrastructure, public health, biodiversity) dimensions in Zemgale Region. Implementation of activities at the demo site have been aimed to demonstrate:

- The framework for turning away from the *ad hoc* activities to **systemic implementation approach** in analysing challenges and solutions, creating pathways for adaptation to the climate change and selection of the consequent strategy for making investments.
- Application of **tailored participatory planning approach** for the stakeholder involvement from public, private and civic sectors to develop a shared vision and pathways for the climate change adaptation in Zemgale Region.
- Covering of the **cross-sectoral dimensions**, e.g., agriculture, forestry, water, energy, environment, tourism, industry within the regional planning aspects.
- Reflection of the **adaptation needs** of municipalities and sectors in the Regional Climate Change Adaptation Plan.
- Appropriate **solutions and actions** for municipalities and sectors are selected and accepted to climate change adaptation planning.

¹ Law on Climate (draft, 21-TA-62), <https://tapportals.mk.gov.lv/structuralizer/data/nodes/06fc406d-ff19-46b5-8036-16781df14439/preview>



2.8.1 Results

Elaboration of the Zemgale Regional Climate Change Adaptation Plan has resulted in a set of **intermediate task outcomes**:

- Status quo overview on risks and adaptation measures at national and local CCA plans within Boreal region (Estonia, Lithuania, Finland and Sweden) to obtain set of climate change aspects as solid basis for further selection of adaptation measures.
- Background on CC risks and adaptation measures in municipal and national planning documents in Latvia.
- Prioritized CC impacts in Zemgale region: economic impact is strongly pronounced for agricultural and infrastructure sector. Social impact is significant for public health and civil protection (related to floods). Resource perspective is a priority for forestry and biodiversity.
- Socio-economic prognosis for development of economic sectors in Zemgale region by 2030.
- Review on vulnerability, interlinkages of impact chains of precipitation, temperature and wind for cross-sectoral assessment highlight the directions where activities for CC adaptation should be tailored. 10 CC adaptation measures are identified for the public health and civil protection, 4 measures for agriculture/forestry sector, 10 measures related to infrastructure and 6 measures for biodiversity maintenance. Performance indicators were selected for each measure.
- Overview on ongoing or planned activities towards CC adaptation at regional and local level collected using an online questionnaire. This information served as a basis for the action plan (chapter in the CCA Plan).

The **task outcome** is a mid-term (7 years) strategic planning document for Zemgale Planning Region that reflects the EU, national and regional CCA policies, regional CC related impacts, socio-economic analyses, priority directions in sectors, action plan - set of measures to be implemented, monitoring and review procedure.

Implementation of **participatory planning approach** resulted in outcomes via stakeholder (SH) engagement during series of workshops (w/s):

- SH w/s 1: Kick-off for elaboration of CCA Plan: informing stakeholders about planning approach and collecting initial ideas on priorities and directions of action to increase CC resilience in the region.
- SH w/s 2: Discussion on CC risks, informing stakeholders on adaptation measures in place at countries within Boreal region, prioritizing CC impacts in Zemgale region.
- SH w/s 3: Adaptation to CC in Zemgale region: priority actions, early warning and knowledge support. Participants discussed applicable actions for Zemgale region in strategic, practical, and informative directions. Stakeholders pointed out that it is very crucial to determine responsibilities and cooperation between national and municipal levels regarding CC adaptation actions - the climate adaptation strategic documents must be connected at all levels.
- SH w/s 4: Discussion on priority directions and actions for CC adaptation considering precipitation, temperature and wind impacts to agriculture, forestry, biodiversity, infrastructure and public health domains. Discussion in the working group allowed to obtain ideas from participants on gaps that are contributing to damage and what strategic, practical, informative measures are needed to address the gaps.
- SH w/s 5: Interactive session on climate change adaptation actions and measures was held. During the working group there were discussions about measures in different sectors aimed to identify implementers of these activities. Priority directions/measures identified match the planning on the national and regional/local levels.
- SH w/s 6: Interactive IMPETUS session with SH on CC adaptation pathways included introduction on hazards related to increased precipitation (flood risk) in the region and discussion on potential measures to reduce the vulnerability (grey/green infrastructure).
- SH w/s 7: Interactive IMPETUS session with SH on SWOT analysis on CC adaptation governance as part of the CCA Plan.
- SH w/s 8: Presentation of IMPETUS results to SH: presentation of the CCA Plan and its content, overview on Adaptation Pathways introduction of RKB offers for the Zemgale region.

Methods, tools, or techniques used

A participatory planning approach was applied engaging stakeholders from national, regional and local levels by applying variety of methods, tools and techniques to keep stakeholders' interest high and fostered the experience exchange during the project events at the same time obtaining inputs from stakeholders for the Zemgale regional climate change adaptation plan:



- **Interaction with stakeholders** via Jamboard was used at early stages of the plan development to capture ideas from local and regional SH on climate change related risks, impacts on the development of various economic sectors in the region.
- **Presentations** by BEF experts at online and face-to-face workshops to introduce good practice examples for CCA adaptation, to reflect the outcomes of previous interactive sessions, etc.
- **Individual contributions** (self-reflection) of stakeholders by voting with sticky dots to prioritise CC impacts in Zemgale region, and to select priority aspects of governance actions needed to change the approach and promote CCA at strategical planning level, practical implementation, awareness and knowledge raising.
- **Individual contributions** (self-reflection) of stakeholders identifying weaknesses that are contributing to CC related damages; strategic, practical, and informative measures that are needed to address these weaknesses.
- **Individual contribution by evaluation** (set of criteria, rating by scores) of possible measures to reduce flood impacts at urban and rural environment.
- **Moderated working group discussions** with stakeholders, e.g., in a World Cafe setting to identify CC impacts and priority directions for CCA, to discuss and select CCA measures for the region.
- **Interaction with SH** via Mentimeter – a survey was conducted asking SH to select priority areas and actions to adapt to the economic, social and environmental impacts of climate change in the Zemgale region.
- **A questionnaire** (online survey) on CCA measures already ongoing/planned in Zemgale region and at local municipalities.

A **Guideline** on tailored participatory planning approach to CC adaptation in Zemgale region is reflected in IMPETUS product.

Key-findings

Adaptation to climate change is becoming increasingly important for public authorities, business and inhabitants. The governance process in Zemgale region is supported by a Climate, Energy and Environment Coordination Working Group established and coordinated by ZPR. The working group consists of representatives from local governments, meeting regularly to discuss issues related to climate adaptation. ZPR has joined the EU Mission "Adapting to Climate Change", gaining access to technical assistance (expert advice) on climate change adaptation issues.

At the same time, it has been acknowledged by stakeholders of Zemgale region that adaptation measures are costly and challenging for municipal budgets; funding from other sources is needed. Socio-economic problems are generally considered a priority, especially in times of crisis. Implementation of CCA measures largely depends on the initiative of individual stakeholders. Insufficient data e.g., on the condition of rainwater drainage and drainage systems hinders the planning process of adaptation measures for flood risk prevention. It has been admitted that information about climate change threats (severe storms, heavy rain, hail, floods) in the region is not communicated quickly enough.

On strategic planning level, there is a need for aligning national, regional and municipal plans to move in a common direction towards achieving climate resilience goals. Development of municipal climate change adaptation plans would be needed to plan the activities in a systemic way at local level. Increasing the knowledge and capacity of residents and local government specialists on actions and measures for adaptation to climate change would increase the readiness for action particularly in occasions of extreme events e.g., storms, heavy rainfalls, high temperatures, floods and draught. On practical level, nature-based solutions for implementation in urban and rural areas should be promoted to increase resilience at local communities along with regular inspection of buildings and old, potentially dangerous trees.

Collaborations and partnerships

The project partners from Latvia BEF, ZPR and JDC were directly contributing to development of Zemgale Regional Climate Change Adaptation Plan. BEF elaborating the content and leading the preparation process, ZPR – having the main role in collection and assessment of data on socio-economic development in Zemgale region, elaborating the chapter on monitoring of the plan, obtaining feedback from municipalities analyses of the region. JDC contributing with information on flood risk early warning system. All implementing partners BEF, ZPR and JDC were involved in addressing SH by contacting them and participating at the events. Municipalities of Zemgale Region were actively contributing by sharing their viewpoints on climate change related risks and impacts, providing information on CCA measures to be implemented at their municipalities.



Outreach activities

The approach for engaging stakeholders and the process of elaboration of the Zemgale Regional Climate Change Adaptation Plan has been presented at the following events:

- “Zemgale Regional climate change adaptation plan, #6CS Zemgale Region, Latvia (Boreal Bio-geographical region)”, by I. Bremere, D. Indriksone, BEF Latvia at the Stakeholder workshop of RESIST project (Interreg BSR, “Regional ecosystems for social innovation & social transformation, 2023 – 2026), online, on 30th May 2024.
- “Engaging stakeholders towards climate change adaptation planning in Zemgale region, Latvia” by I. Bremere, D. Indriksone, BEF Latvia at the Sustainability Research and Innovation Congress 2024, session “Moving beyond scientific excellence: Mainstreaming transdisciplinary approaches in climate and WEFE nexus policy and practice for wider societal impacts”, online, on 11th June 2024.

2.8.2 Impact

Implementation of the Task 4.24. at Zemgale region demonstrated:

- The framework for turning away from the *ad hoc* activities to **systemic implementation approach** in analysing challenges and solutions is underlying the Zemgale Regional Climate Change Adaptation Plan.
- Application of **tailored participatory planning** for the stakeholder involvement from public, private and civic sectors through series of SH workshops and use of variety of methods, tools and techniques to keep stakeholders’ interest high.
- **Cross-sectoral dimensions** as part of the regional planning process.
- Needs and possibilities to CC adaptation for taking actions at regional and local level.
- Selection and **readiness for uptake** of CC adaptation measures by municipalities and planning region.

Output indicators

- Developed regional plan on adaptation to climate change “Zemgale Regional Climate Change Adaptation Plan”: planned 1, achieved 1.
- Meetings and other events with stakeholders at the demo site – stakeholder workshops: planned 4, achieved 8.
- Lessons-learned report on stakeholder involvement in demo site “Guideline on tailored participatory planning approach”: planned 1, achieved 1.

Outcome indicators

- Regional community has adopted a pathway for climate change adaptation reflected in the plan: planned 1, achieved 5 priority directions for action.
- Accepted solutions for climate change adaptation reflected in the plan: planned 10, achieved 37 types of measures.
- Stakeholder groups involved in co-creation activities for elaboration of set of measures for climate change adaptation thus strengthening the cooperation in the region: planned 10, achieved 8 groups (municipalities, planning regions, regional agencies, research, NGOs, business, ministries, consultants).

Impact indicator

Systemic approach and cross-sectoral dimensions for adaptation to climate change is taken up in strategic planning documents of the Region. “Zemgale Regional Climate Change Adaptation Plan” will be adopted by the Council of Zemgale Planning Region and incorporated as a chapter in Development Strategy.

Advancing the objectives

Implementation of the Task 4.24 was adding to advances for **objectives of the IMPETUS project** and has contributed to generation of substantial impacts as result of the DS#6:

1. **Increased knowledge base of local authorities to prevent and avert flooding risks and disasters** was useful for elaborating measures that can be taken up by municipalities to protect human health and life from the adverse effects of climate change. Elaboration of the CCA Plan has started with desk research on status quo, data collection and analyses on risks and adaptation measures in municipalities of Zemgale Region, as well as on national level in Latvia and in other countries in Boreal bio-geographical region. This has resulted in substantiated set of climate



change aspects to form a solid basis for further selection of adaptation measures by municipalities. In addition, the information is available at the Boreal RKB to ensure further accessibility.

2. **Uptake of integrated Nature Based Solutions (NBS) by local authorities** is incorporated in the CCA Plan by measures for increasing resilience of infrastructure and buildings to climate change. All municipalities in Zemgale Region are either planning or are already implementing corresponding measures including those at the urban areas. Uptake of NBS for climate change adaptation in urban areas was in focus at the IMPETUS event (organized in synergy with the LIFE LATESTadapt project) to more than 60 participants on 05-06.06.2025., in Riga, Latvia.
3. **Applicability of participatory decision support system to planning of climate change resilience** is demonstrated throughout the task implementation. Active participation of stakeholders was ensured at the consultation, prioritization, co-creation, co-design, and empowering stages during the CCA Plan development. IMPETUS approach has demonstrated that engaging stakeholders from an early stage of planning is crucial to achieve acceptance of measures for implementation.

Output of the Task 4.24 is in line with the **WP4 objectives**, as the Zemgale Regional CC Adaptation plan by its design is aimed to help decision makers at municipalities and region to make better informed decisions for selection of adaptation solutions. The plan integrates the IMPETUS knowledge into Zemgale regional development strategies and thus ensures continuity for CC adaptation measures after the project duration.

The **Bundle 4 objectives** on Governance Models, Awareness and Behavioural Change are advanced through the CCA Plan governing climate risk management as well. One of the priority directions included in the plan aims to foster the cooperation of municipalities, to increase knowledge of municipality experts and inhabitants, and to coordinate implementation of measures at the regional level. In Latvia, Zemgale Planning Region is amongst front-runners to tackle the climate change adaptation issues at regional level. The Joint Climate, Energy and Environment Coordination Group was established in 2022, and it serves as a powerful tool for outreach, cooperation and awareness raising among municipalities.

Objectives of the demo site in Zemgale region were set to develop climate resilient innovation packages and adaptation pathways used for further policy and decision-making, raising awareness, enhancing behavioural change, and for the development of adaptation measures towards climate change. The CCA Plan is responding to these objectives by selection of adaptation measures in close fit with the stakeholder participatory activities.

Scalability and adaptability

The scale for implementation of the Task 4.24. is a **regional setting** demonstrated by the Zemgale Regional CC Adaptation Plan. Design of the regional document, however, incorporates the local perspectives for mitigation of CC related vulnerabilities at municipalities. The **local context** provides framework for local authorities to make better informed decisions and investments. Thus, the scalability for implementation of the CCA measures is largely at the local level while the regional level authority (i.e., Zemgale Planning Region administration) ensures integration of strategic development planning and coordination tasks for the region. Adaptation of the planning approach from Zemgale Planning region to others – Riga, Kurzeme, Vidzeme and Latgale Planning Regions in Latvia could be a reasonable effort due to common legal requirements from the national authorities, and supported by the coordination group structure (e.g., Joint Climate, Energy and Environment Coordination Group) within the regional setting. On a **larger scale**, the set of CCA measures reflected in the Zemgale Regional CC Adaptation plan have prime relevance to the Boreal region by the climatic and environmental conditions. Thus, the adaptability of results can be extended for neighbouring countries supported by the networking and experience exchange activities.

Adaptability of methods for participatory planning approach has a good potential at the regional level setting in wide territorial coverage. Involving stakeholders from the early stages of planning by informing and consulting them and later engaging in co-creation and co-design steps while finally empowering them to uptake the results is a generic sequence for implementation. Application of diverse communication methods and tools allows respect for local context factors and discussion culture in setting of CCA priorities and potential measures.

However, the approach to the Zemgale Regional CCA Plan has certain limitations:

- The planning period of midterm document (7 years) is rather limited to demonstrate the effectiveness for implementation of activities.
- The regional plan sets the framework for SH to make better informed decisions and investments; however, implementation of measures at the local level largely depends on priority decisions of local governments and funding available. Therefore, early incorporation of diverse perspectives for mitigation of CC related vulnerabilities at municipalities are essential for acceptability to the implementation.



2.8.3 Lessons Learned

Key takeaways

The Zemgale Regional CC Adaptation Plan provides a rich set of information for mitigation of CC related vulnerabilities at municipalities and reflection of participatory planning approach at the regional level.

- Climate risk management in the Zemgale region is supported by already established governance models and active engagement of Zemgale Planning Region in CC adaptation and mitigation initiatives on national and international level.
- By having a devoted regional level authority, Zemgale Planning Region is capable to integrate the IMPETUS knowledge on CC adaptation activities into regional development strategies and plans ensures continuity of activities after the project duration.
- Engaging diverse SH groups in co-creation provides an advantage for bridging the academic knowledge and practical know-how for selection and prioritization of CC adaptation measures.
- Participatory planning approaches by various SH engagement methods motivates participants to active discussions, exchange of viewpoints and mitigation of potential conflicting interests.
- This solution has the potential to be replicated by applying the methodology of participatory planning to governance, awareness raising and behavioural change in setting the climate change adaptation priorities and measures.

Challenges encountered

Due to delayed implementation of adaptation pathways (in WP5) only limited utilization of synergies to implementation of Task 4.24 for development of the Zemgale regional CCA plan were applicable. Assessment of the CC related risks and identification of the CC adaptation measures for the region was largely based on the stakeholder considerations. Results of adaptation options and alternative pathways, as developed in WP5, are annexed to the Zemgale Regional CCA Plan document.

Future recommendations

- The Zemgale Regional CCA Plan comprises a set of measures for implementation at municipalities and the region. Acknowledging the importance of funding sources for implementation we would recommend strengthening the cost-benefit component of CC adaptation measures elaborated in future projects.
- Development of the Zemgale CCA Plan was strongly supported by a regional coordinating body having close contacts with municipalities and other local stakeholders. We would recommend involving regional partnership institution for outreach of stakeholders in the planning.

Barriers to transferability

Potential for replication is seen in countries (Boreal region) having regional level governance setting.

2.8.4 Conclusion

Zemgale Regional CC Adaptation Plan provides comprehensive ground for **taking an action at regional and local level** to increase resilience against climate change related impacts and risks. The Plan comprises **5 priority directions with 37 types of measures** envisaged. Participation of stakeholders from national, regional and local levels provided ground for the exchange of opinions and perspectives. Diverse **stakeholder engagement** methods supported keeping stakeholders' interest high and fostered the experience exchange during the project events.

2.9 Decision Support Tool for Industrial Decarbonisation (Task 4.25)

European climate policies aim for net-zero GHG emissions by 2050, requiring a major transformation of the **industrial sector**, which contributes around **21% of Europe's emissions**. This shift is especially complex in **industrial clusters**, where shared infrastructure and interconnected systems present both opportunities and challenges. The Port of Rotterdam (PoR) is the Europe's largest port and a key economic hub and it is a prime example, as it hosts a dense network of **emission-intensive industries**. While shared systems enable potential collaborative decarbonisation, **investment risks, policy uncertainty, and technological limits** make the transition difficult. Defining clear decarbonisation pathways is thus essential to support the energy transition in PoR and similar clusters. Examples of these potential investment strategies for decarbonisation include:

- Fuel switching through the use of hydrogen and electrification.
- Carbon Capture Storage (CCS) solutions.



- Adoption of circular economy practices such as waste heat recovery and energy efficiency improvements.

Knowledge gaps

One of the critical barriers in industrial decarbonisation is the absence of clear decision-making frameworks that effectively integrate economic, technical, and policy considerations. Decision-makers need tools capable of assessing multiple decarbonisation pathways while also evaluating their financial and environmental implications. This requires a deep understanding of the interactions between industries, energy sources, and emission reduction strategies to support an adaptive approach. Considering these problems, current gaps can be summarized as follows:

- **Fragmented decision-making:** industries lack integrated tools that evaluate multiple decarbonisation pathways from both economic and environmental perspectives.
- **Limited industrial synergies:** existing models do not adequately capture interdependencies between industries, often leading to isolated solutions.
- **Uncertainty in the economics of decarbonisation technologies:** high infrastructure costs and regulatory uncertainties hinder investment in low-carbon solutions.
- **Lack of prioritization of decarbonisation solutions:** a wide range of decarbonisation scenarios leads to overwhelm decision-makers, making it difficult to determine where to start or what to prioritize when decisions have to be taken.

To overcome these challenges, there is a need to develop **Decision Support Tools (DSTs) and digital twin technologies** that provide an interactive platform for industries and policymakers. These tools should support the analysis of carbon reduction strategies by integrating technological options, economic implications and decision-making frameworks. By supporting the decision-making process for a wide range of potential industrial investments, DSTs plays a crucial role in enabling the effective decarbonisation of industrial clusters and advancing the broader energy transition across the EU industry.

Task objectives

The proposed solution involves the development of an interactive tool to support industries within the Atlantic demo site, specifically the Port of Rotterdam, in assessing decarbonisation pathways, optimizing investments, and contributing to climate risk mitigation. The specific objectives of the task are as follows:

- Identify decarbonisation pathways for different processes within the industries and clusters in the PoR.
- Develop simulation models to assess carbon reduction potential, physical and energy flows, and provide economic insights across a wide range of decarbonisation scenarios.
- Develop simulation models to enhance wastewater treatment processes focused on energy efficiency and waste heat utilization within the Chlorine Cluster.
- Implement a Multi-Criteria Decision-Making (MCDM) framework that identifies and prioritizes the best decarbonisation alternatives based on predefined evaluation criteria.
- Implement Geographic Information System (GIS) base visualizations to represent baseline scenarios, including carbon emissions, potential residual heat, and energy consumption patterns.
- Develop an interactive and user-friendly dashboard interface that enables stakeholders to dynamically identify, explore and assess decarbonisation strategies.

2.9.1 Results

Task outcomes

- A **comprehensive analysis** of the various industries and clusters was performed to identify potential pathways for industrial decarbonisation. Alternatives included hydrogen adoption, electrification, CCS, fuel biomass, and shifting to zero-gap membrane strategies. Stakeholders contributed to the validation of the decarbonisation pathways for different processes in the PoR.
- **Models** were developed to quantify and simulate carbon emissions, physical and energy flows, and financial implications related to the potential decarbonisation pathways for different industries within the PoR. The main components of these models include the Chlorine Cluster with companies such as Nobian, Huntsman, Westlake, Shin-Etsu, and Refineries, such as Shell, Esso, and BP (Figure 17).



- [illegible]

- **Models** were developed to unify various innovative technologies into an integrated wastewater treatment process, with the aim of enhancing energy efficiency and waste heat utilization within the Chlorine Cluster (Figure 19). This integrated approach promotes industrial symbiosis, supports the

circular economy, and contributes to the decarbonisation efforts. The models build upon valuable outcomes and insights gained from the WATER-MINING project.

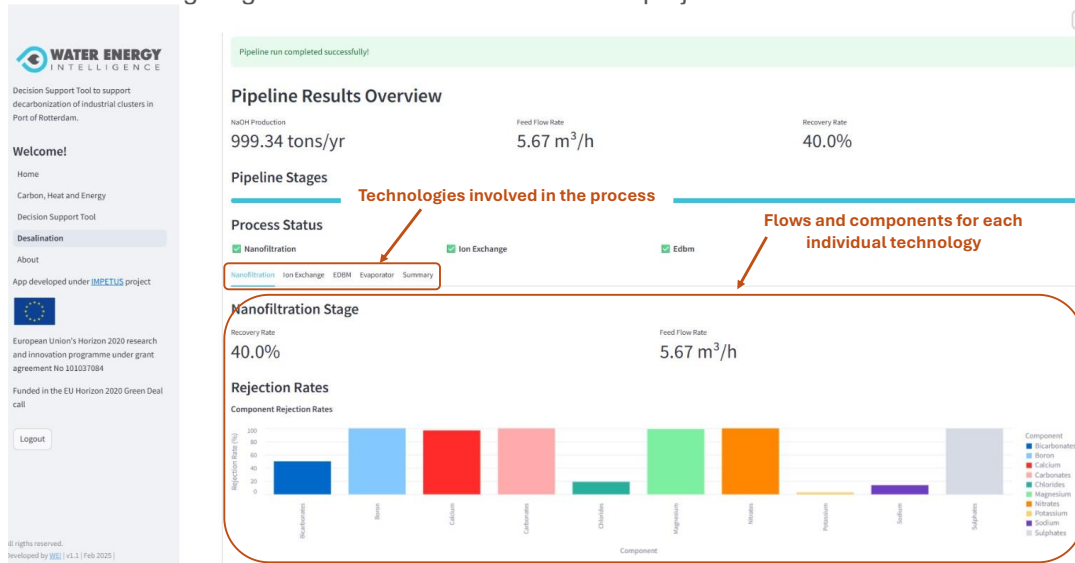


Figure 19: Integrated wastewater treatment and resource recovery process.

- **GIS-based spatial visualizations** were integrated to map baseline scenarios, including carbon emissions, residual heat potential, and energy patterns for both the Netherlands and the PoR (Figure 20). These visualizations provide stakeholders with a tool to identify hotspots and support targeted decarbonisation actions at both regional and local levels.

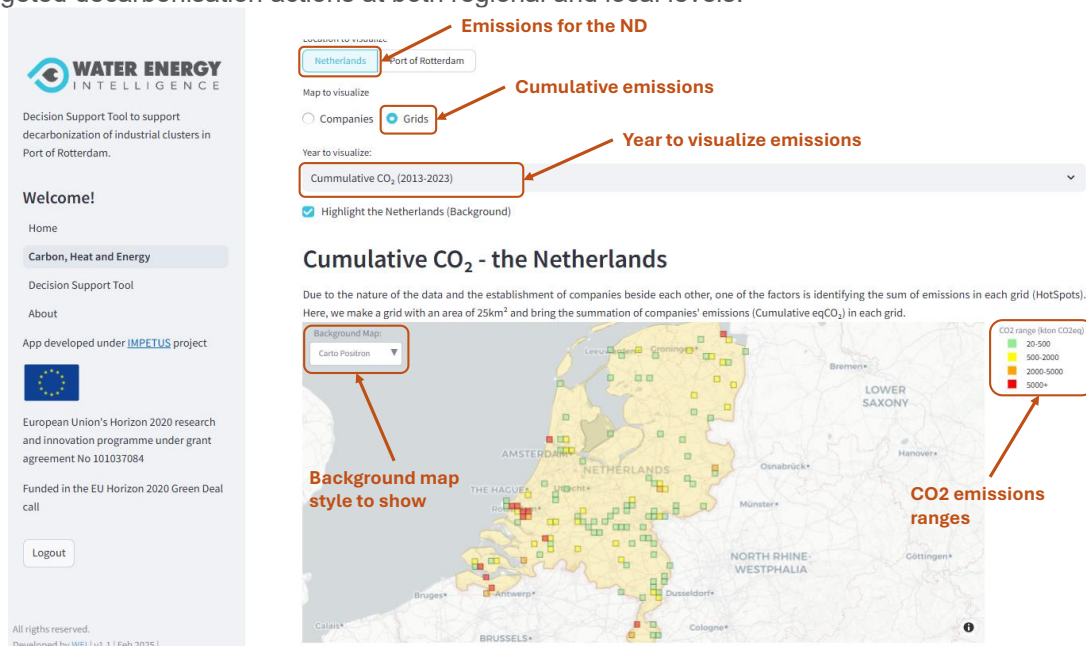


Figure 20: GIS visualization of baseline scenarios for carbon emission in the Netherlands.

- An **interactive online dashboard** interface was developed to host and execute all the models, features, and processes, providing a dynamic decision-making functionalities tailored to stakeholders.

The developed DST includes all the aforementioned features and facilitates industrial decarbonisation in the PoR. It enables scenario modelling for industrial actors and clusters to perform scenario-based modelling, assessing range of potential strategies and emissions reduction pathways. The tool represents the main result of this task and is accessible at: dashboard.weintelligence.eu.

Methods, tools, and techniques used



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101037084.

The methods and techniques applied in this task comprise several steps, which are structured and developed as follows:

- A **comprehensive analysis** of various processes within industries and clusters was performed to identify potential pathways for industrial decarbonisation in the PoR.
- **Stakeholder interaction**: actors were identified and structurally grouped to understand their roles and implications within the decarbonisation scenarios.
 - a. The Community of Practice: local stakeholders were engaged to facilitate their involvement in the development of the tool, data validation, and contribution with key information about the potential decarbonisation pathways for industries in the PoR.
- **Model development**: models were developed using consecutive approaches and software programs, each of them contributing to the final version of the tool.
 - a. Basic model conceptualization: an extensive analysis of literature was conducted to identify the existing models and areas for improvement
 - b. An initial model was developed using Linny-R software with the objective of understanding the interactions between actors within the clusters.
 - c. Due to stakeholder feedback regarding the model's initial complexity, Python was subsequently used to operate the model, providing a robust framework for simulating various decarbonisation scenarios.
 - d. The model was refined completely in Python (improving its architecture for replicability) to enhance ease and accessibility, thereby achieving broader usability among stakeholders.
- **Model development** for wastewater treatment process: based on the insights and Community of Practice from WATER-MINING project, models for wastewater treatment processes were developed in Python and adapted to the DST.
- **GIS and data visualization**: GIS techniques were employed to map spatio-temporal carbon emissions and to identify potential residual heat sources and energy consumption patterns.
- **Best-Worst method**: this method was incorporated as part of the tool's decision-making framework to help decision-makers rank and prioritize complex investment and decarbonisation strategies, adding a robust analytical layer to the DST.
- **Dashboard development** and refinement: an interactive and user-friendly dashboard was developed using Python and Streamlit and deployed online through Heroku, allowing accessibility to decision-makers to dynamically explore various decarbonisation strategies and compare them with baseline scenarios.

The functional structure of the DST is summarized in Figure 21. It begins with the input of the initial data, including production parameters, specific process's configuration, and relevant emission factors. The tool then generates outputs detailing decarbonisation outcomes across various possible scenarios. In the next step, stakeholders identify the technical criteria most relevant to their context. Based on these preferences, the BWM is applied to provide detailed information about the scenarios that best aligns with their needs.

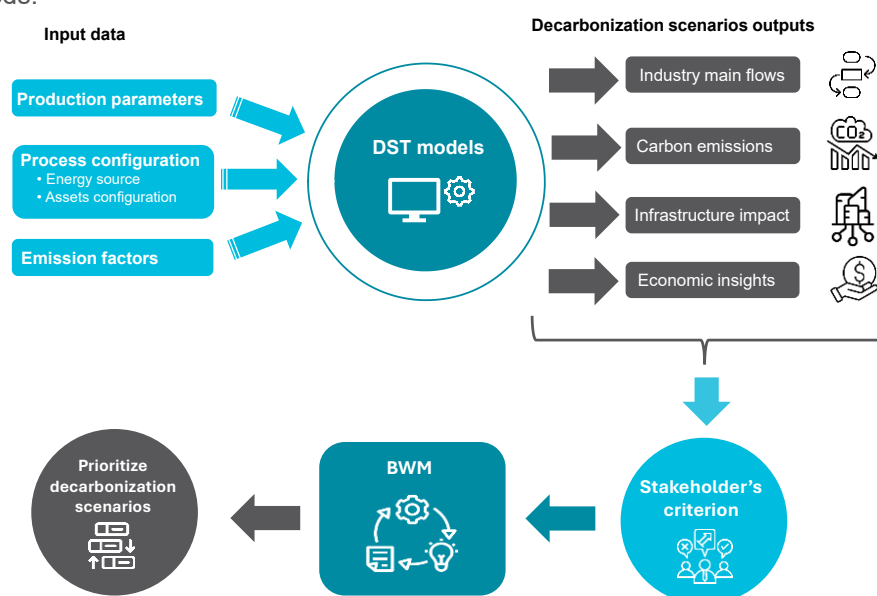


Figure 21: Functional structure of the DST models.

The methodology for this task incorporates the development of the DST and stakeholder interaction to create a tool that guides the decarbonisation of industrial clusters. This approach enables continuous model improvement tailored to the needs of decision-makers.

Interactions

The development of the tool required interaction with local stakeholders in the PoR to validate data and refine its functionality. This step was essential for improving the usability and accuracy of the tool. In parallel, additional feedback was gathered through interaction with academic and industrial experts. Participants included stakeholders and experts from TU Delft, Siemens, Quintel, Stedin, Tennet, Shell, Exxon, Quo Mare, Kalavasta, Port of Rotterdam, RVO/Ministry of Economic Affairs, Nobian, and Westlake. These engagements were key to incorporating diverse technical perspectives and aligning the tool's capabilities to stakeholders' expectations.

Outreach

During the execution of the project, sessions were organized with stakeholders to demonstrate the tool's capabilities and gather feedback from end-users. These sessions also explored potential future practical implementations of the tool to address decarbonisation challenges. Outreach also included the following activities:

- Oei, L. H. D. (2022). Technology adoption at the PoR chlorine cluster: A study on the effect of market & behavioural barriers on technology adoption at the Port of Rotterdam chlorine cluster [Master's thesis, Delft University of Technology]. TU Delft Repository. <http://resolver.tudelft.nl/uuid:6732e066-a3c0-4be5-ae0e-89fdbb058354>
- Yasin Sagdur (2022). Decision Support Tool for Decarbonisation of the Industry Clusters (Case Study: Port of Rotterdam). Conference presentation. Online
- Pedram Rezaei (2025). Sustainability Impact Assessment and Smart Decision-Making for Decarbonizing Industry Clusters. Water Smart Economy & Society Congress, organized by TU Delft. Rotterdam, The Netherlands.

A new series of sessions, organized with stakeholders in the PoR, is expected to take place in the coming period (even after the project's completion), with showcasing the tool's capabilities as a priority to obtain feedback and encourage their use in future decarbonisation projects.

2.9.2 Impact

Implications and potential impacts

The development of the DST fulfils the initial task objectives by providing an interactive digital platform that enables stakeholders to **asses and rank decarbonisation strategies** in the PoR. The integration of scenario modelling, economic implications, and technical perspectives enhanced the decision-making process, allowing industries to evaluate and optimize their transition to low-carbon alternatives. The development of this tool was also carried out with the interaction and engagement of industrial actors, ensuring that the tool aligns with real-world needs.

The short-term effects of this solution include **increased stakeholders awareness and knowledge shared** on a range of potential decarbonisation pathways for the industrial cluster in the PoR. Additionally, the tool was developed to satisfy as many needs as possible based on feedback from stakeholders throughout the project. In the long term, the tool is expected to be used by decision and policymakers to **support the industrial decarbonisation efforts**. It is expected that within five years of the project's completion, 20% of the companies in the PoR will adopt the DST to guide decarbonisation strategies.

The outcome of this task aligns with the IMPETUS project goals by providing stakeholders and policymakers with instruments and adaptation strategies to support climate risk mitigation. In particular, within the Bundle 4 (Governance Models, Awareness, and Behavioural Change), this task contributes to innovations based on digital technologies and the integration of models to promote industrial decarbonisation through a relevant decision-making approach. Similarly, within the Atlantic Demo Site (Zeeland & Rijnmond), this solution also provides a replicable digital framework that enhances industrial climate adaptation, with the potential to reinforce national and regional climate policies while advancing decarbonisation initiatives related to climate change adaptation.

Transferability, scalability and adaptability

The DST provides stakeholders with an interactive tool for informed decision-making on decarbonisation. The developed models and features within the tool software were designed on a **modular design**, enabling scalability and adaptability across different contexts. The tool provides a flexible and customizable architecture that can be adopted and replicated in other industrial settings



beyond the PoR. Although, transferability to other contexts is possible, it requires further research and adaptation efforts to account for industry-specific processes and local conditions. This **limitation** to direct transferability arises also because not all industrial processes are the same, and different conditions vary by location, including the accessibility of technical data, technological availability, investment capabilities, and other factors.

Limitations and best practices

The software tool's effectiveness relies on access to **accurate industrial and technical data** regarding the processes being modelled. In regions where technical data is not readily available, assumptions can be made using other similar industrial processes. The best practice for adapting the tool to new contexts would be to engage and work closely with local stakeholders to refine and validate the data on scenarios and potential technologies for decarbonisation. This supports climate risk mitigation and maximize synergies between different industrial sectors.

2.9.3 Lessons Learned

Key takeaways

The DST has proven to be a valuable resource that can be used for industrial decarbonisation, demonstrating that **evidence-based modelling** enhances decision-making and raises awareness among both industry stakeholders and policymakers. **Stakeholder involvement** and interaction play a crucial role in refining the tool's usability, as direct collaboration with industrial actors ensured that the DST aligned with real-world constraints and operational needs. Furthermore, while our tool integrates a range of decarbonisation technologies, certain limitations such as infrastructure needs, technology readiness, economic feasibility, and policy support, act as major determinants of their large-scale deployment.

Challenges

A significant challenge in developing this task was **access to industrial information**; several industries were reluctant to share detailed operational data due to concerns about confidentiality and potential business risks, which limited the model's accuracy. A mitigation action to overcome this issue was the use of publicly available datasets and industry reports to fill data gaps. Additionally, the **complexities of inputs** provided by multiple stakeholders posed another challenge. Industries, policymakers, and researchers had divergent priorities, requiring iterative adjustments to refine the DST features and satisfy expectations. Furthermore, integrating different industrial processes into the tool required significant time and effort, considering that each process is unique to its respective industry and faces unique decarbonisation challenges.

Future recommendations

To enhance the DST's functionality, it is essential to integrate features that allow for **scenario adjustments** based on policy implications and market fluctuations, particularly through methods to assess long-term impacts. This includes the development of automated updates for CO₂ pricing mechanisms and subsidy frameworks, such as carbon reduction subsidies, which will improve the usability of the tool for industrial stakeholders. Additionally, strengthening **data-sharing agreements** with industries is crucial; establishing confidentiality frameworks and secure data-sharing mechanisms can facilitate more accurate integration of data. Lastly, the DST should expand to include **broader industrial symbiosis strategies**, such as shared energy networks and frameworks for waste heat utilization. Over the coming period, partners will continue to develop and refine the tool and, most importantly, by collaborating with Rotterdam Port stakeholders.

Barriers to transferability

The tool relies on unique industrial parameters and decarbonisation challenges for the PoR cluster, providing valuable insights for the demo site. However, the direct transferability of this approach may not be straightforward due to the **limited availability of data** in other regions. A tailored methodology may be required to adapt this solution to other industrial settings, making it suitable to local conditions in different contexts. This challenge also involves the availability of **specific decarbonisation technologies**, infrastructure, and other elements that were specifically considered for this solution. Furthermore, **regulatory differences** across regions pose a challenge, as carbon pricing, energy policies, and industrial regulations vary, requiring further research for local adaptations.

2.9.4 Conclusion

The task resulted in a **Decision Support Tool (DST)** that aids stakeholders in tackling industrial decarbonisation, particularly in the **Port of Rotterdam**, by enabling the exploration of various scenarios, assessing carbon reduction potential, and evaluating financial and infrastructural impacts. Developed through stakeholder engagement, the **DST is user-friendly**, adaptable to future technologies, and aligned with EU climate policies, making it valuable for broader industrial clusters beyond the port. It bridges the **gap between policy and decision-making** and offers a structured framework for implementing decarbonisation strategies. Future work may enhance **data integration** and expand **industry participation** to increase the tool's impact.

3 Conclusions

Across the seven IMPETUS demonstration sites, the adaptation solutions implemented under Bundle 4 collectively highlight the importance of **governance innovation, stakeholder engagement, and behavioural change** as essential pillars of climate-resilient development. Although the solutions differ in scope – from viticulture and water governance to cultural heritage, tourism, marine planning, greenhouse agriculture and industrial decarbonisation – they reveal strong commonalities in how institutions, communities, and decision-makers can navigate climate uncertainty through **participatory, data-driven approaches**.

A first insight is that **place-based climate information**, when combined with long-term monitoring and digital tools, significantly strengthens adaptive capacity. Whether assessing altitude-dependent warming in vineyards (**Task 4.17**), simulating real-time water management scenarios through the Berlin Water Model (**Task 4.18**), or integrating climate projections into marine spatial planning (**Task 4.19**), climate data becomes actionable when translated into **formats that stakeholders can understand and use**. This confirms the value of coupling scientific modelling with participatory processes to ensure local relevance and uptake.

Secondly, all tasks demonstrate that **co-creation and multi-level governance** are powerful enablers of adaptation. Workshops, exercises, story maps, digital twins and joint scenario analyses foster shared understanding among authorities, practitioners, businesses, and citizens. The project results on tourism (**Task 4.22**), climate risk governance (**Tasks 4.23 and 4.24**), and industrial decarbonisation (**Task 4.25**) shows how collaborative approaches not only improve decision-making but also **reduce conflicts over resource use and align adaptation goals across sectors**. These participatory processes consistently increased stakeholder ownership and improved the social acceptability of adaptation actions.

Thirdly, the solutions reveal that **behavioural and cultural dimensions are as crucial as technical ones**. Insights from cultural heritage (**Task 4.21**) highlight how values, traditions, and lived experiences influence risk perception and acceptance of adaptation measures. Similarly, the tourism and agriculture tasks (**Tasks 4.20 and 4.22**) illustrate how awareness, incentives, and communication tools can **shift behaviours toward more resilient practices**. These findings reaffirm that effective adaptation depends on understanding the human systems that shape vulnerability and resilience.

Finally, the tasks underline that **scalability and transferability depend on simplicity, transparency, and institutional anchoring**. Tools and methods that are intuitive, interoperable, and aligned with local planning frameworks (such as the Berlin Masterplan Wasser and the Zemgale regional CCA Plan) show the greatest potential for long-term uptake. Digital tools (e.g., decision support tools, shared libraries and repositories, interactive dashboards) are highly transferable when they are developed with clear governance frameworks and sustained stakeholder engagement.

All in all, the main findings and lessons learnt from the bundle's solutions can be summarise as follows.

Main findings:

- **Participatory and co-creation approaches** proved essential for climate resilience, enabling stronger ownership of solutions by local authorities, businesses and communities.
- **Behavioural change initiatives** (e.g. awareness campaigns, tourism engagement, citizen science) demonstrated that knowledge-sharing and empowerment lead to more sustainable practices, but require long-term reinforcement.
- **Governance frameworks** that integrate climate adaptation into territorial and sectoral planning (urban, tourism, agriculture, coastal, etc.) improve policy alignment and cross-sector cooperation.



- **Digital platforms and decision-support tools** facilitated data accessibility, knowledge transfer, and transparency, thereby strengthening collaboration and reducing conflicts over resource management.
- The **transferability potential** is high when methodologies (e.g. co-design processes, decision-support systems, participatory planning) are flexible enough to be adapted to different socio-economical contexts.

Lessons learnt:

- **Stakeholder engagement** works best when inclusive and continuous; sporadic involvement risks losing momentum, especially with smaller grassroots actors.
- **Transparency in data sharing** remains a recurring barrier; technical tools help, but governance agreements are crucial for trust.
- **Iterative approaches** allow adjustment to local realities and make outcomes more realistic and impactful.
- **Behavioural change** requires persistent effort, tailored communication and integration into broader governance strategies to become lasting.
- **Scalability** depends on combining technical innovation with institutional buy-in; solutions need not only to work technically, but also fit governance structures and community values.
- **Cross-sectoral collaboration** (e.g. tourism plus climate adaptation, water management plus agriculture) generates synergies and avoids fragmented efforts.

Overall, IMPETUS Bundle 4 solutions show that **governance innovation and behavioural change** are as crucial as technical and nature-based solutions for effective climate adaptation. The solutions' strength lies in their **replicability, adaptability, and ability to connect** local actions with broader policy frameworks.

Table 4: Overview of main impact, transferability and scalability of the described adaptation solutions.

TASK	IMPACT	TRANSFERABILITY	SCALABILITY
Task 4.17 Evaluation of the Effects of Altitudinal Shift of Crops on Vineyards	Improved understanding of how altitude shapes grape quality and phenology to provide operational guidance for vineyard adaptation.	The integrated approach can be easily replicated in other wine regions, especially those with altitudinal gradients.	Indicators such as Growing Degree Days (GDD), Growing Season Temperature (GST), and frost/heat stress indices are standard and can be computed anywhere to support regional or national climate adaptation planning.
Task 4.18 Stakeholder Workshops	Strengthened data-driven decision-making by demonstrating how the water model can assess climate risks and management options in real time to enhance cross-sectoral collaboration and political engagement.	The live modelling component can be applied elsewhere to simplify complex systems, build trust in scientific tools, and support co-design of solutions with local decision-makers.	The method of integrating scenarios with an existing masterplan is highly scalable at different levels, e.g. helping regions to embed scientific modelling directly into regional policy processes.
Task 4.19 Co-Design a Marine Spatial Framework	Enhanced participatory marine spatial planning by involving stakeholders in a co-design process that considered future climate scenarios, environmental sustainability, and economic activities.	The framework developed can be adapted to other coastal or marine regions facing similar climate risks, particularly where balancing ecological preservation and	Modular and replicable design: stakeholder-driven approach and digital mapping tools can be scaled to larger areas or integrated into national and transnational initiatives.



		human activities is required.	
Task 4.20 Multi-Purpose Controlled Environmental Agriculture	Reduced water use, better irrigation efficiency, improved aquifer monitoring and data-driven decision-making.	Applicable in other agriculture-intensive, water-scarce regions.	Scalable with proper infrastructure and digital capacity.
Task 4.21 Cultural Heritage as a solution to enable Climate Resilience	<i>Intangible:</i> Preserved traditional practices while enhancing adaptive capacity; innovation through rooted knowledge. <i>Tangible:</i> Improved comfort and energy performance of historic buildings under future climates.	<i>Intangible:</i> Transferable to wine-producing regions valuing heritage. <i>Tangible:</i> Applicable to similar historic buildings across Europe	<i>Intangible:</i> It requires context-specific heritage practices and stakeholder buy-in. <i>Tangible:</i> Modular solutions, scalable with available funding and technical support.
Task 4.22 Pursuing Behavioural Change for Climate Resilient Tourism	Awareness raised among local tourism stakeholders about climate risks and fostering a culture of climate-conscious decision-making in the sector. Vulnerabilities and adaptive capacities identified in the local tourism system, enabling a shared vision for long-term climate resilience.	The participatory methodology is applicable to other tourism-dependent regions, particularly in areas sensitive to climate change.	Simplicity and flexibility of engagement tools and techniques used: easily scaled up or down depending on the size and complexity of the tourism system, and integrated into regional or national strategies for climate adaptation in tourism.
Task 4.23 Improving Integrated Climate Risk Assessment and Management through IC Approach	Strengthened local governance, raised awareness, activated new institutional collaborations.	Participatory methods and tools adaptable to other mountain regions with similar governance challenges.	It requires facilitation capacity and contextual adaptation.
Task 4.24 Establishment of a Climate Change Adaptation Plan Governing Climate Risk Management	Enabled systemic planning with stakeholder co-creation and cross-sectoral integration.	The methodology fits other regions seeking multi-sectoral CCA plans.	Institutional alignment and existing planning frameworks ease scalability.
Task 4.25 Decision Support Tool to Support the Decarbonisation of Industrial Clusters	Interactive digital platform developed to help stakeholders assess and rank decarbonisation strategies for the industrial cluster in the Port of Rotterdam.	Transferability to other contexts is possible, but it requires further research and adaptation efforts to account for industry-specific processes and local conditions.	Modular design, enabling scalability and adaptability across different contexts. Flexible and customizable architecture that can be adopted and replicated in other industrial settings.

4 Outlook and Recommendations

This section provides forward-looking and practical recommendations based on the diverse adaptation solutions presented in Section 2. These recommendations aim to support long-term robustness, transferability and institutional uptake. They are specific yet adaptable across contexts and sectors.

Technical recommendations:

- **Strengthen digital platforms** by integrating real-time environmental, social and economic data, ensuring alignment with existing planning frameworks. User-centred visualisation and scenario tools (such as those tested in water management, agriculture, tourism, and marine planning) should be further developed to translate complex information into decision-ready insights.
- **Improve monitoring and evaluation systems** by embedding feedback loops into digital tools, governance processes and sectoral planning instruments. Continuous data collection (e.g. climate, hydrological, agronomic, cultural heritage indicators) is essential for adaptive management and early detection of emerging risks.
- **Prioritise user-friendly, modular design** in all technical solutions to enhance uptake among non-experts, including local communities, SMEs, and public officials. Tools that are intuitive, transparent and interoperable show the highest potential for scale and long-term use.

Operational recommendations:

- **Institutionalise participatory methods** (such as co-design workshops, impact chain exercises, living labs and stakeholder dialogues) into routine governance processes. The experience across demo sites shows that early and consistent engagement increases ownership, reduces conflicts, and strengthens the legitimacy of adaptation measures.
- **Enhance data transparency and sharing protocols**, establishing clear responsibilities for data management, ownership and maintenance. Open-data principles should be promoted while balancing privacy, security and institutional constraints.
- **Promote continuity in behavioural change initiatives** by linking campaigns to long-term education, training and communication programmes. Findings from tourism, cultural heritage, agriculture and industry tasks highlight that behavioural and cultural dimensions are critical drivers of adaptation success.

Collaboration-oriented recommendations:

- **Foster multi-level governance integration**, aligning local adaptation actions with regional, national and EU strategies. This helps avoid fragmentation, ensures policy coherence and facilitates the formal uptake of project tools into planning frameworks.
- **Build communities of practice across sectors** (such as water management, agriculture, tourism, cultural heritage, forestry and coastal management) to exchange lessons, sustain partnerships and enable replication of successful approaches.
- **Encourage cross-border and cross-region collaboration**, especially where climate risks (e.g. droughts, floods, heat stress, landscape changes) transcend administrative boundaries. Joint scenario planning and coordinated adaptation pathways improve resilience and resource efficiency.
- **Lower participation barriers for underrepresented stakeholders**, including small farmers, grassroots organisations, cultural practitioners and local citizens. Tailored communication, incentives and accessible formats foster inclusion and ensure that adaptation measures reflect diverse needs and capacities.

Implementing these recommendations will:

- Increase the effectiveness, relevance and long-term sustainability of adaptation solutions.
- Strengthen trust, transparency, and shared ownership among stakeholders.
- Enhance transferability and scalability beyond the demo site contexts.
- Ensure solutions remain flexible and adaptive to evolving climate, socio-economic, and institutional conditions.

In conclusion, future initiatives should **integrate technical innovation, operational mainstreaming, and collaborative governance** to transform project achievements into lasting, systemic change across regions and sectors.



5 Annex

5.1 Figures and Tables about Task 4.17

Here are collected the Figures and Tables of the Task 4.17, described in Section 2.1 on Evaluation of the effects of the altitudinal shift of crops on vineyards.

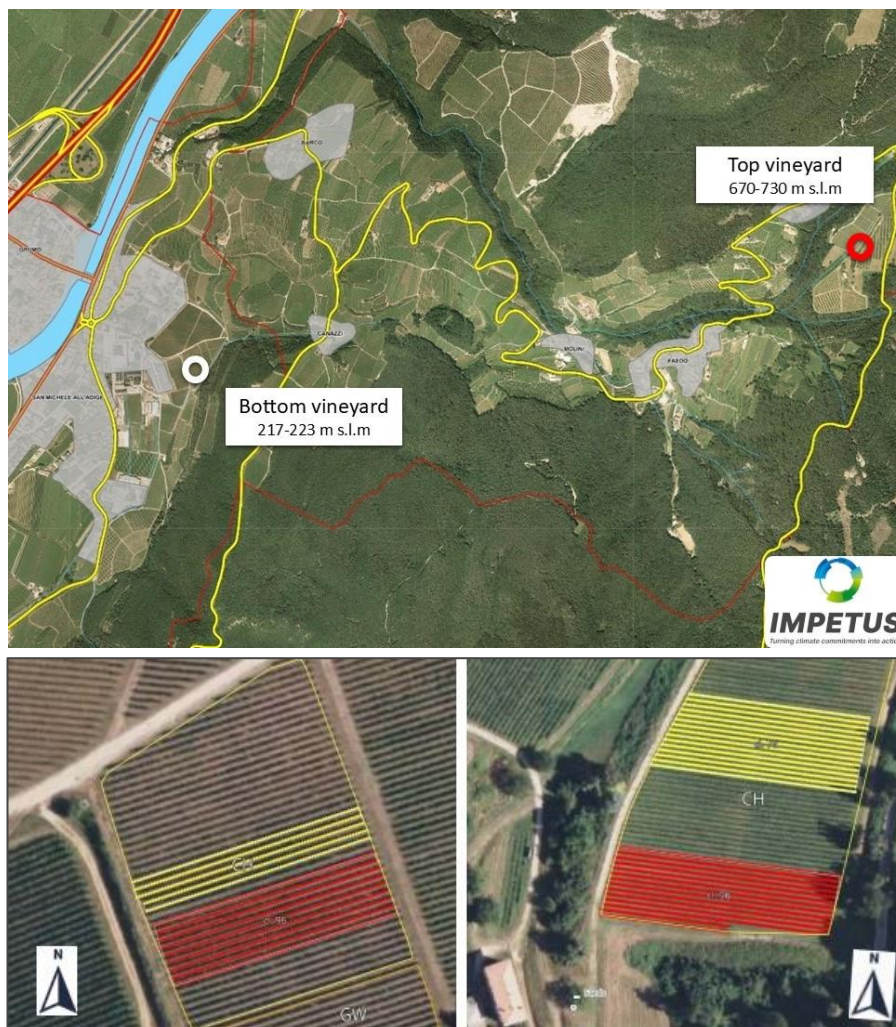


Figure 22: Map of the vineyards with the plots and plants highlighted. ("Bottom" on the left, "Top" on the right).



Figure 23: Damage from late spring frost 2024.

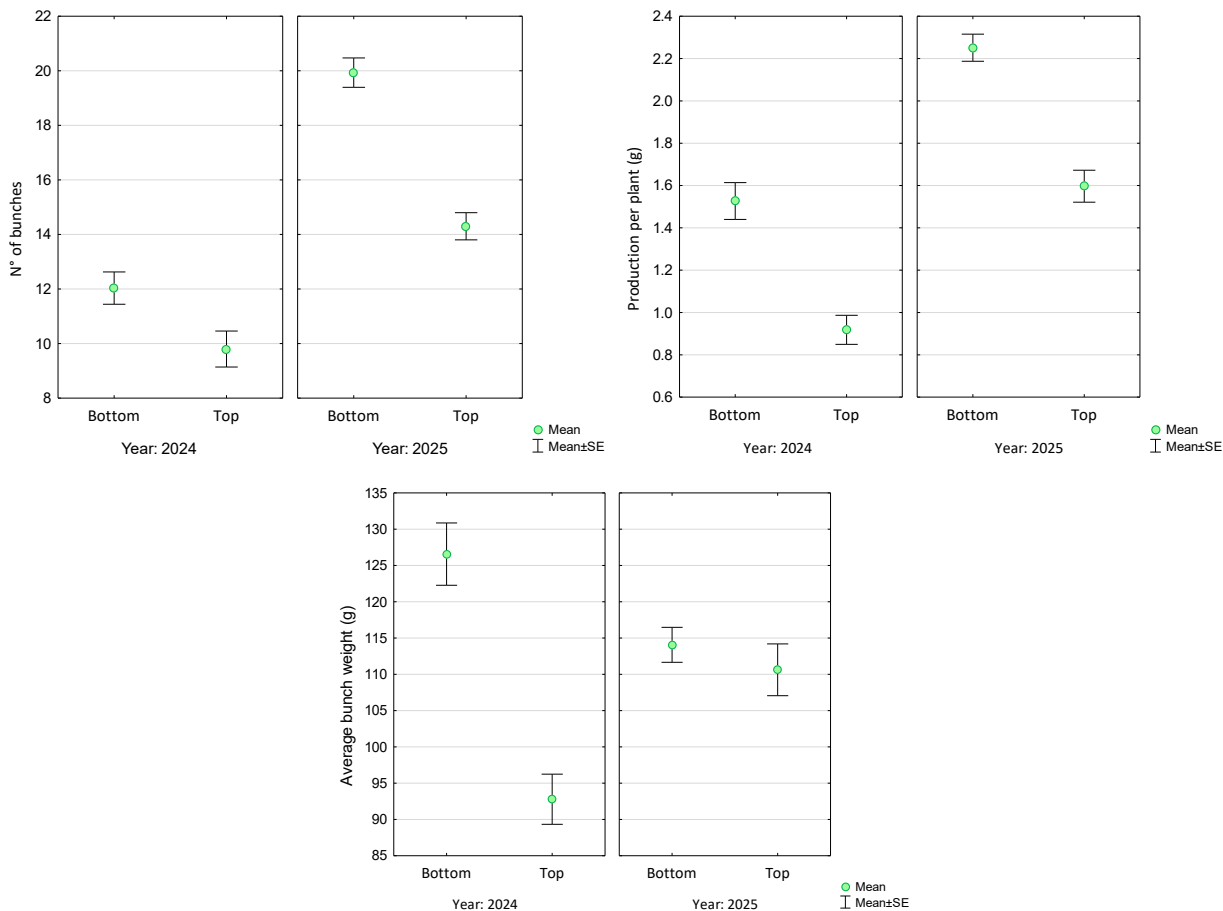


Figure 24: Effect of vineyard and year factors on production data.

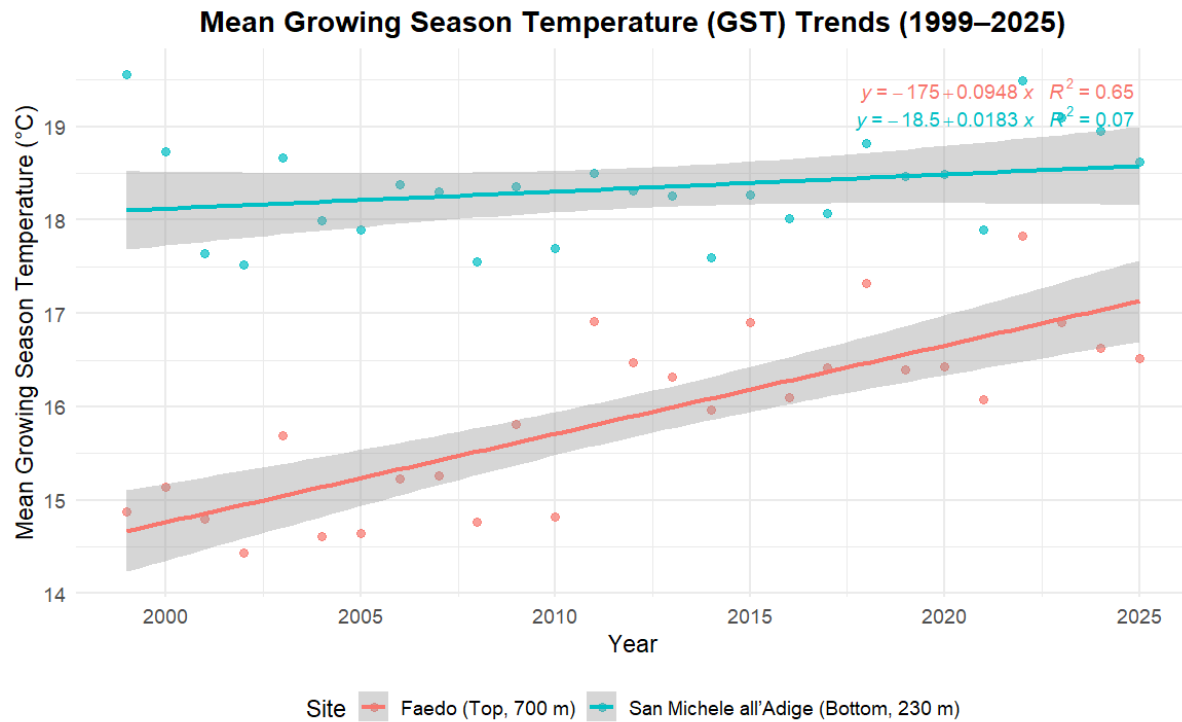


Figure 25: Increasing growing season average temperature (GST) reflects local warming, 1999–2025.

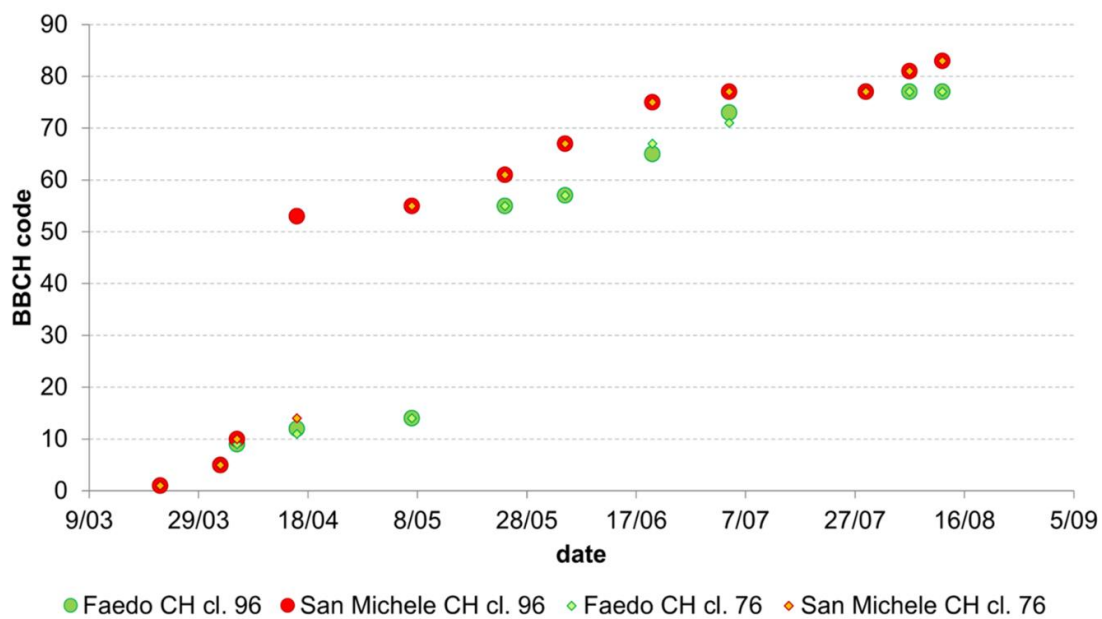


Figure 26: Phenological development at the two sites of San Michele all'Adige (bottom - red) and Faedo (top - green) for the two clonal selections (cl. 76 – diamond and cl. 96 – circle).

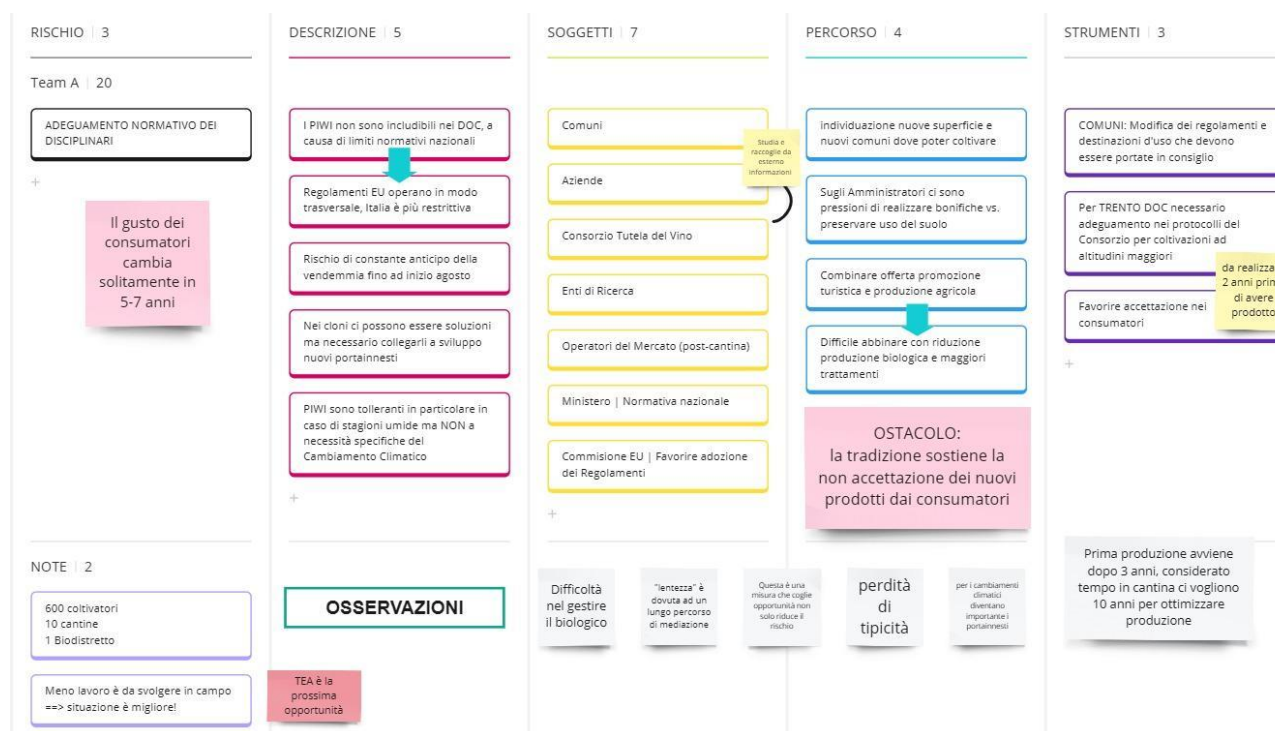


Figure 27: Example of canvas results (from stakeholder workshop).

Table 5: Leaf analyses carried out at veraison in 2024.

	N tot. (%)	P tot. (%)	K tot. (%)	Ca tot. (%)	Mg tot. (%)	Fe tot. (mg/kg)	Mn tot. (mg/kg)	B tot. (mg/kg)	Zn tot. (mg/kg)
BOTTOM cl. 76	2.15	0.2	1.51	3.41	0.3	80	90	37	41
BOTTOM cl. 99	2.27	0.22	1.36	3.69	0.36	73	73	34	24
TOP cl. 76	2.23	0.18	0.78	3.26	0.5	82	165	53	27
TOP cl. 96	2.14	0.15	0.83	3.25	0.42	76	183	41	25
Reference standards (*)	1.80- 2.70	0.09- 0.30	0.70- 1.60	2.30- 3.90	0.22-0.47	40-220	35-220	16-41	10-90

(*) Porro et al. (2001)

Table 6: Statistical significance of factors on bud fertility and optical indices.

(ANOVA, Tuckey test)			
Factor	Bunches/shoot	SPAD index	NDVI index
Year	***	***	***
Vineyard	*	n.s.	n.s.
Clone	n.s.	***	***



Table 7: Statistical significance of factors on production data (ANOVA, Tukey test).

Factor	N° of bunches	Production/plant (g)	Average bunch weight (g)
Year	***	***	n.s.
Vineyard	***	***	***
Clone	**	n.s.	***

Table 8: Compositional differences of musts (biennial means).

	° Brix	Reducing sugars (g/l)	pH	Total acidity (g/l)	Tartaric acid (g/l)	Malic acid (g/l)	Potassium (g/l)	YAN (mg/l)
2024	17.7 b	174 b	3.02 b	9.68 a	6.70	5.64 a	1.26 b	110 a
2025	19.9 a	198 a	3.21 a	8.53 b	7.65	4.28 b	1.77 a	81 b
Top	18.2 b	178 b	3.01 b	10.5 a	7.75 a	5.81 a	1.40 b	113 a
Bottom	19.5 a	194 a	3.23 a	7.75 b	6.60 b	4.11 b	1.64 a	78 b

Different letters indicate statistically significant differences ($p < 0.05$); the absence of letters indicates a lack of significance.

Table 9: Summary of climatic differences between the top and bottom experimental vineyards over the 1999-2025 period (data from the weather station network managed by the Agrometeorology and Irrigation Unit of the CTT FEM).

Variable	Top/shoot	Bottom	Implication
GDD	1320	1770	Bottom site warmer, longer growing season
GST	15.9 °C	18.3 °C	Bottom site generally warmer
Spring Frosts	0.96/year	0.56/year	Top site more frost-prone
Hot Days	0.33/year	4.04/year	Bottom site hotter, potential heat stress
Heavy Rain	6.63/year	5.41/year	Top site slightly wetter events
Longest Dry Spell	15.2 days	15.9 days	Similar drought risk

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