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# D1.4 WP1 testing results



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| D1.4: WP1 testing results | | |
|---|---|---|
| **Summary** | | |
| Deliverable 1.4 of project ICARIA is the main outcome of Task 1.4 (WP1 lab testing of methods and tools). Some of the methodologies and tools developed in WP1 will be tested and applied using initial, representative data provided by the three (3) case study regions (AMS, SLZ, and SAR) to verify their readiness and robustness for the current set of methodologies and to provide a rigid scaffold for lab testing in the following WPs (WP2/D2.4 and WP3/D3.6). | | |
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## List of Acronyms and Abbreviations

| | |
|---|---|
| AIT | Austrian Institute of Technology |
| AMS | Barcelona Case Study |
| AMR | IPCC's Sixth Assessment Report |
| CMIP5 | Coupled Model Intercomparison Project Phase 5 |
| CORINE | Coordination of Information on the Environment |
| CS | Case Study |
| CFS | Case Study Facilitator |
| CFSs | Case Study Facilitators |
| D | Damage |
| D# | Deliverable Number (#) |
| DSS | Decision Support System |
| E | Exposure |
| GIS | Geographic Information System |
| GDP | Gross Domestic Product |
| H | Hazard |
| HEDMO | Hellenic Electricity Distribution Network Operator S.A. |
| IAMs | Integrated Assessment Models |
| IPC | Intergovernmental Panel on Climate Change |
| IPCC | Panel on Climate Change |
| Lat | Latitude |
| Long | Longitude |
| RCM | Regional Climate Model |
| SAR | South Aegean Region |
| SLZ | Salzburg Case Study |
| SSO | Strategic Subobjectives |
| SSPs | Shared Socioeconomic Pathways |

| | |
|---|---|
| V | Vulnerability |
| WP(s) | Work Package(s) |

# Executive summary

This document outlines the initial ICARIA's lab tests regarding WP1 activities and offers a brief application and evaluation on treating specific data gaps and identifying additional data sources. ICARIA, through the establishment of a robust and efficient framework for climate adaptation and resilience, aims to provide methodologies for data gap treatment for multi-sectoral impact assessment in the context of complex multi-hazard scenarios characterized by compound events and cascading impacts. In this sense, the evaluation, applicability, and ultimately the transferability of any methodologies remains key. This document focuses on lab experiments with respect to selected data gaps within ICARIA case studies, serving as a testbed for further applications of the "*cookbook*" (see D1.3) within CSs modelling applications. Nonetheless, selecting an optimal combination of various methodologies to address data gaps represent a complex challenge when applying fully quantitative impact models for impact assessment in a multi-hazard framework (see D1.1). In fact, it is far from uncommon to encounter issues where data scarcity emerges, especially for assets and services linked with proprietary and security conditions. Consequently, the role of lab tests is to identify and choose one crucial data gap group for each area of study and to apply a potentially optimal methodology, ultimately guiding and contributing to the formulation of effective decision-making policies. Further, it remains key to consider that data gaps introduce substantial uncertainties hindering the development of effective resilience measures capable of invariance in various contexts. To support addressing the critical challenge of data gaps, within ICARIA's goals, methodologies from previous tasks are being employed in the lab test cases where the need to extend and support the currently chosen ones, remains necessary. Four (4) lab tests are listed including the following data gap groups: (i) AMB (Barcelona area): Land use (based on data gaps on population density, deforestation, and information on spatial areas, (ii) AMB: Pluvial floods (based on data gaps on urban drainage infrastructure, sea level, wave height, and tide measurements, electricity asset's location, heatwave and heat island effect modeling and vulnerability curves, (iii) SLZ (Salzburg area): Windstorm and flooding (based on data gaps on data on damaged areas (cellars, floors, and related costs) per identified event, damaged road network, impacted infrastructure, damaged electricity grids, and broken and/or fallen trees), and (iv) SAR (South Aegean area): Forest fires (based on data gaps on road network, power grid, water distribution network characteristics, and reparation costs per property damaged). Each lab test presents a comprehensive scheme for addressing the data gaps outlined identified data gaps, key selection criteria, applied methodologies and synthetic tables to evaluate results. Moreover, it provides sets of supplementary sources for assets and services, as examples for further application and replications across other areas of interest within the ICARIA's project, including additional lab tests in trials and mini-trials.

This deliverable is the first result of T1.4 with inputs from T1.1, T1.2, and T1.3, in WP1, T2.1 in WP2, and T7.2 in WP7.

# 1 Introduction to project ICARIA

The number of climate-related disasters has been progressively increasing in the last two decades and this trend could be drastically exacerbated in the medium- and long-term horizons according to climate change projections. It is estimated that, between 2000 and 2019, 7,348 natural hazard-related disasters have occurred worldwide, causing 2.97 trillion US$ losses and affecting 4 billion people (UNDRR, 2020). These numbers represent a sharp increase of the number of recorded disaster events in comparison with the previous twenty years. Much of this increase is due to a significant rise in the number of climate-related disasters (heatwaves, droughts, flooding, etc.), including compound events, whose frequency is dramatically increasing because of the effects of climate change and the related global warming. In the future, by mid-century, the world stands to lose around 10% of total economic value from climate change if temperature increase stays on the current trajectory, and both the Paris Agreement and 2050 net-zero emissions targets are not met.

In this framework, **Project ICARIA** has the overall objective to promote the definition and the use of a comprehensive asset level modeling framework to achieve a better understanding about climate related impacts produced by complex, compound and cascading disasters and the possible risk reduction provided by suitable, sustainable and cost-effective adaptation solutions.

This project will be especially devoted to critical assets and infrastructures that are susceptible to climate change, in a sense that its local effects can result in significant increases in cost of potential losses for unplanned outages and failures, as well as maintenance – unless an effort is undertaken in making these assets more resilient. ICARIA aims to understand how future climate might affect life-cycle costs of these assets in the coming decades and to ensure that, where possible, investments in terms of adaptation measures are made up front to face these changes.



To achieve this aim, ICARIA has identified 7 Strategic Subobjectives (SSO), each one related to one or several work packages. They have been classified according to different categories: scientific, corresponding to research activities for advances beyond the state of the art (SSO1, SSO2, SSO3, SSO4, SO5); technological, suggesting and/or developing novel solutions, integrating state-of-the art and digital advances (SSO6); societal, contributing to improved dialogue, awareness, cooperation and community engagement as highlighted by the European Climate Pact (SSO7); and related to dissemination and exploitation, aimed at sharing ICARIA results to a broader audience and number of regions and communities to maximize project impact (SSO7).

- SSO1.- Achievement of a comprehensive methodology to assess climate related risk produced by complex, cascading and compound disasters
- SSO2.- Obtaining tailored scenarios for the case studies regions

- SSO3.- Quantify uncertainty and manage data gaps through model input requirements and innovative methods
- SSO4.- Increase the knowledge on climate related disasters (including interactions between compound events and cascading effects) by developing and implementing advanced modeling for multi-hazard assessment
- SSO5.- Better assessment of holistic resilience and climate-related impacts for current and future scenarios
- SSO6.- Better decision taking for cost-efficient adaptation solutions by developing a Decision Support System (DSS) to compare adaptation solutions
- SSO7.- Ensure the use and impact of the ICARIA outputs

# 2 Objectives and context of Deliverable 1.4

WP1 focuses on framing ICARIA's methodologies, climate scenarios, modeling requirements and addressing data gaps and uncertainty. A key component of the general framework includes creating templates for treating data gaps to support hazard, exposure and vulnerability analysis, and data uncertainty analysis. Thus, the last task of WP1 is dedicated to testing the templates, particularly for data-gap treatment. Task 1.4, along these lines, will help to achieve:

- Establishing an initial template for identifying and testing data gaps tailored to the area of study.
- Characterize the data gaps and identify the most viable and accurate methodologies to treat the specific kind of data gap.
- Evaluate the applicability and limitations of the chosen methodology and unravel any potentially hidden data gaps.

Task 1.4 has the objective of defining the lab test scenarios for targeted data gaps and analyzing each selected gap type. The present D1.4 document summarized the work needed and the aforementioned results to obtain a first indication of treating data gaps as the main objective to provide an example template of choosing datasets and methodologies, and to explain the specific processes undertaken to characterize the targeted data gaps.

**Table 1:** Test organization in Task 1.4.

| Test | Issue | Case Study | Partners involved |
|---|---|---|---|
| A | Downscaling of SSP Shared Socioecomonic Pathways to Case Study Scale (AMB Case Study) | AMB | CETAQUA/FIC |
| B | Application of synthetic data generation methods for data gap filling in urban drainage & flooding models | AMB | AQUATEC |
| C | Impacts of windstorms and fallen trees on road network of rural/peri-urban areas | SLZ | AIT |
| D | Resilience assessment tools on specific CI of islands (e.g., ports, airports…) | SAR | DMKTS |

Furthermore, it aims at gathering information from relevant sources or creating synthetic information when data sources are scarce or restricted. Also, this deliverable is a key component in understanding data gaps and their potential repercussions. To achieve its objectives, the document is structured in a way that aims to provide detailed information for each test compactly, summarizing the objectives of the test, informing on data collection, and data gaps, the employed methodology, and finally presenting the activities and results therein. The list explaining the lab tests of the deliverable, namely, the Metropolitan Area of Barcelona, the Salzburg Region and the South Aegean Region, representative of the data gap for each case study area, are summarized in Table 1.

# 3 Methodology followed

Each lab test employs a unique methodology tailored to address the targeted data gap. Therefore, some current methodologies developed in previous tasks within Work Package 1 (WP1) of the ICARIA project, must be tested to initially validate the applicability of the studied data gap and to prepare a scaffold for the following lab test within the project when input will be gathered from trails and mini-trials. The lab tests adhere to the subsequent methodologies:

**Lab test A** focuses on temporal series derived from land cover data, studied using the ARSINOE method (ARSINOE Project, 2021), which was introduced and initially verified in previous tasks in WP1 for the definition of climate projections and hazard scenarios. The objective is to downscale shared economic pathways by providing a framework of socioeconomic and development trajectories followed by a combination of socioeconomic challenges, resulting in regional-level scenarios. The input comprises time series datasets sourced from the CORINE (Coordination of Information on the Environment) database for land cover, including quantitative descriptors (e.g., Gross Domestic Product (GDP), population density, etc.), to study the land use dynamics. The freely available datasets include land cartographic representations integrated with Socioeconomic pathways (SSPs) for representative projections and used based on the outcomes of the case studies utilizing GIS-based models. The output aims to understand local land use data and choose the optimal SSPs. Selections of factors and descriptors play a key role in evaluating dynamics, detecting changes and estimating the land cover demands. The process results in providing a probability of land use change in the form of land use projections, of estimating the suitability of each land sector and the land demands, as illustrated by land use maps of the characteristics of interests (e.g., flood damages, water demand, etc.).

**Lab test B** focuses on pluvial floods and on estimating the drainage system characteristics when data are scarce or unavailable. For that purpose, 1D/2D hydrodynamic models are applied to assess the risk associated with the pluvial floods for a series of 28 municipalities in the Barcelona area. While both models represent the drainage capacity of the sewer network, datasets representing the characteristics of the 1D model — such as manholes, pipes, and inlets— are often scarce or inaccessible due to proprietary or security constraints. These models aim to analyze demographic and geometric characteristics such as land use, population and street morphology and integrate these findings with the analysis of the sewer network characteristics, estimating parameters based on limited data. The output will offer a framework for studying pluvial floods and overpassing data gaps related to the sewer network, facilitating for application in other urban areas.

**Lab test C** focuses on windstorms and forest loss. Data for historical events of windstorms are collected and the monetary damage for such events aimed to be estimated, linking intensities to observed data. Thus, the test attempts to deal with the scarcity of datasets for tree characteristics, as a key data gap. The methodology comprises three steps: (I) evaluating the current state of the freely available datasets from several sources and determining the amount of input that requires estimation by expanding methodologies introduced in previous tasks within the WP1, (ii) the combination of datasets to categorize and locate each tree, resulting in maps depicting tree locations, and (iii) to apply the extraction process across all Salzburg administrative 2 level districts. The methodology is designed to be sensitive and specific, as only trees within a threshold distance can be included to provide some reasonable output for the estimation of the monetary damage to the infrastructure (e.g., the road network), using a proposed buffer zone along the road lines of 80 meters (10-20 meters of the road itself extended by approximately 20-30 meters in addition to each side). Finally, data gap groups related to damage—such as data on damaged areas, road network conditions right after the flooding or the windstorm event, the number of affected or broken trees and infrastructure damage—are estimated.

**Lab test D** focuses on forest fires and infrastructure vulnerability by collecting geospatial data to perform vulnerability analysis for road networks, power grids and economic damages on buildings, focusing on expanding the current knowledge by activating the regional databases and identifying the extent of the data gaps in both geospatial and socioeconomic types. Additionally, economical vulnerability is estimated using the taxable fair market value for the buildings and the average cost per kilometer of road restoration. The method aims to identify each infrastructure type within the damaged area from the 2023 forest fire, which occurred on Rhodes Island, highlighting assets vulnerable to forest fires. Due to limited regional data, the methodology compiles a two-step scheme, involving the continuous search for updated preparation costs and the use of alternative economic data. The method's output is summarized in a vulnerability analysis map, where the areas with the highest likelihood of being affected by the forest fires are depicted and a characterization of the extension of vulnerability per asset is listed.

# 4 Tests developed

## 4.1 Test A: Downscaling of SSP Shared Socioecomonic Pathways to Case Study Scale (AMB Case Study)

### 4.1.1 Summary and Objectives of Test A

Lab Test A aims to test one of the methodologies available in the literature to downscale the Shared Socioeconomic Pathways (SSP) projections to adjust to the local reality. The SSPs are a set of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) to explore potential future socioeconomic trajectories and their implications for greenhouse gas emissions and climate change mitigation and adaptation. These scenarios, outlined in the IPCC's Sixth Assessment Report (AR6) released in 2021, provide a framework for analyzing the complex interplay between socioeconomic factors, climate policies, and environmental outcomes.

The SSPs are based on narratives that describe alternative socioeconomic developments, encompassing elements such as population growth, urbanization, economic growth and technological progress. These qualitative storylines are complemented by quantitative data on national-level indicators, including population, urbanization rates and gross domestic product (GDP) per capita. The narratives and quantitative data serve as inputs for Integrated Assessment Models (IAMs), which are computational tools used to explore the potential pathways of socioeconomic and climate systems under different assumptions and policy scenarios. The IPCC has defined five distinct SSP scenarios, each representing a unique combination of socioeconomic challenges for mitigation and adaptation:

- **SSP1**: Sustainability ("Taking the Green Road") – This scenario depicts a future characterized by sustainable economic growth, rapid technological progress, and effective international cooperation, leading to reduced inequalities and a focus on environmental protection.
- **SSP2**: "Middle of the Road" – This scenario represents a continuation of historical patterns of development, with moderate progress in achieving sustainable development goals and a balanced emphasis on economic growth and environmental protection.
- **SSP3**: Regional Rivalry ("A Rocky Road") – This scenario envisions a future marked by fragmented international cooperation, prioritization of regional interests and slow economic growth, resulting in challenges for both mitigation and adaptation efforts.
- **SSP4**: Inequality ("A Road Divided") – This scenario depicts a future with significant disparities in economic and technological development, both within and across countries, leading to uneven progress in addressing climate change.
- **SSP5**: Fossil-fueled Development ("Taking the Highway") – This scenario assumes rapid economic growth driven by the exploitation of fossil fuel resources, with limited efforts to mitigate greenhouse gas emissions and adapt to climate change impacts.

By exploring these diverse socioeconomic pathways and their implications for climate change, the SSPs provide a valuable framework for researchers, policymakers and stakeholders to assess the potential consequences of different development trajectories and inform decision-making processes related to climate change mitigation and adaptation strategies. The main objectives of Lab Test A are:

- Match data gaps in the CS modelling framework that can be fed with a methodology from the ICARIA cookbook
- Define and detail SSP projections to the adequate territorial reality
- Include SSP scenarios into a local/region scale projection model

**Table 2**: Test A summary.

| Test A summary | | | |
|---|---|---|---|
| **Methodology** | ARSINOE | **Data-gap** | Temporal series regarding CORINE Land Cover Data |
| **Hazard** | N/A | **CS of the test** | AMB |

## 4.1.2 Summary and Objectives of Test A

List of identified data gaps tested in Lab test A and justification

Land use demands, historical land use maps and the estimation of the ease-of-change are used in order to calculate the variation in land use over time for the AMB region, utilizing data from the CORINE land cover database. To ensure a comprehensive and accurate analysis, four time-series datasets have been carefully chosen, spanning the years 2000, 2006, 2012 and 2018. While a dataset for the year 1990 is available, it has been intentionally excluded from the analysis. This decision is grounded in the exceptional event of the 1992 Olympic Games hosted in Barcelona, which could potentially introduce significant noise and variability in various land use types during that period.

Mega-events like the Olympic Games often trigger substantial infrastructure development, construction of sporting venues and temporary accommodations, leading to substantial land use changes. These changes may not accurately reflect the long-term trends and patterns of land use in the region, thereby skewing the projections and analysis. By excluding the 1990 dataset, the study aims to mitigate the potential impact of this outlier event, ensuring that the land use variations captured are representative of the region's natural evolution and development trajectories. This approach enhances the robustness and reliability of the analysis, enabling more accurate projections and informed decision-making.

The selected time-series datasets, spanning from 2000 to 2018 at regular intervals, provide a comprehensive and consistent temporal coverage, allowing for the identification of long-term trends and patterns in land use dynamics. This methodological decision underscores the study's commitment to rigorous scientific principles and the pursuit of accurate and meaningful insights into the AMB region's land use dynamics. Data on GDP and population density were also incorporated as the qualitative descriptors and numeric inputs for the method included in the cookbook for SSP downscaling. These data were retrieved from the IDESCAT (in Spanish Instituto de Estadística de Cataluña). A criterion for choosing among the different SSPs was retrieved from the criteria exposed in ICARIA D1.2 (ICARIA, 2024a). The predictors' list used as an example for lab test A is shown in Table 3:

**Table 3**: Factor descriptor.

| Factor descriptor |
|---|
| Growth per capita |
| Urbanization |
| Deforestation |
| Irrigated Surface Area (ha) |
| Area covered with water intensive crops (ha) |
| Abandonment of land |
| Subsistence agriculture |



**A detailed description of the methodology**

**Downscaling method**

In pursuit of the objectives for this lab test A, a methodology predicated upon the utilization of projected land-use cartographic representations has been deemed the optimal approach. This stratagem would facilitate a more veracious depiction of the territorial actuality inherent to the selected climate prognostications by incorporating the narratives delineated within the SSPs into the projections. The ramification of this approach entails the calibration of the potential socioeconomic outcomes to a more precise evaluation of the impacts assessed within the purview of the ICARIA project endeavor, with particular emphasis on the AMB Case Study. The proposed methodology draws inspiration from the socioeconomic downscaling approach espoused by the ARSINOE project (CE, 2021), as well as the scholarly endeavors of Huber García et al. (2018), both already mentioned in ICARIA Deliverable 1.2 (ICARIA, 2024a). This modus operandi is predicated upon the downscaling of the selected SSP by employing present and future projections of local land-use data and GDP information.

The inaugural phase necessitates the judicious selection and characterization of the pertinent SSPs. It is proposed to identify the principal SSP deemed representative of the circumstances prevailing within the case study. An additional factor to consider in characterizing and selecting the appropriate SSP is the evaluation of various strategic adaptation plans for each case study. This approach aids in standardizing the criteria employed in the selection of the SSP and augments awareness of the potential outcomes, thereby facilitating the assessment of the accuracy of this methodology. All the ARSINOE case studies have selected the SSP1-26 and SSP3-70. The SSP1-26 is considered an optimal choice as its lower boundary remains within (or at least in close proximity to) the scenario proposed by the EU-Green Deal targets. The SSP3-70 has recently been considered as an upper boundary climate and socioeconomic future that (i) contrasts the "green" scenario and thus opens/covers a broad feature space of possible pathways; (ii) is fairly close in warming potential to the CMIP5 RCP8.5; (iii) is scientifically novel (one of the pilots) and publishable. The objective of this phase is then to choose the SSP that best suits the future socioeconomic scenarios for each case study.

However, the SSPs selected for the current project are yet to be determined after a proper evaluation, in order to better suit the purposes of ICARIA project. The second step involves the selection of different factors/descriptors to characterize the distinct scenarios. These criteria consider two important approaches: (1) A qualitative selection of factors/descriptors that would establish the partial relations between the possible results in both scenarios and (2) A quantitative estimation of the parameters that describe the previous factors used to characterize the SSP to be able to include them in the aforementioned projections. These factors/descriptors are chosen through the consensus of a multidisciplinary panel of experts, taking into account strategic plans, data availability in the different study cases, and other criteria deemed relevant within the literature. A selection of the parameters to be included in the projection model will also be carried out based on the state of the art and availability. Once these scenarios have been described and characterized, the subsequent step involves the establishment of a model that allows for the projection of the change of a desirable characteristic. The model considers the effects of the previously chosen parameters to constrain the possible outcomes of our simulation within the limits of the chosen SSP.

The existing GIS-based models, such as CLUEMONDO (Van Asselen et. al. 2013; Gao et. al. 2022) or iCLUE (Verweij et al. 2018), proposed in the ARSINOE project, will be evaluated for application in ICARIA for land use time-scaled projections. These tools aid in incorporating local SSPs into the outcome of the projections. These models require the following inputs (see Figure 1):

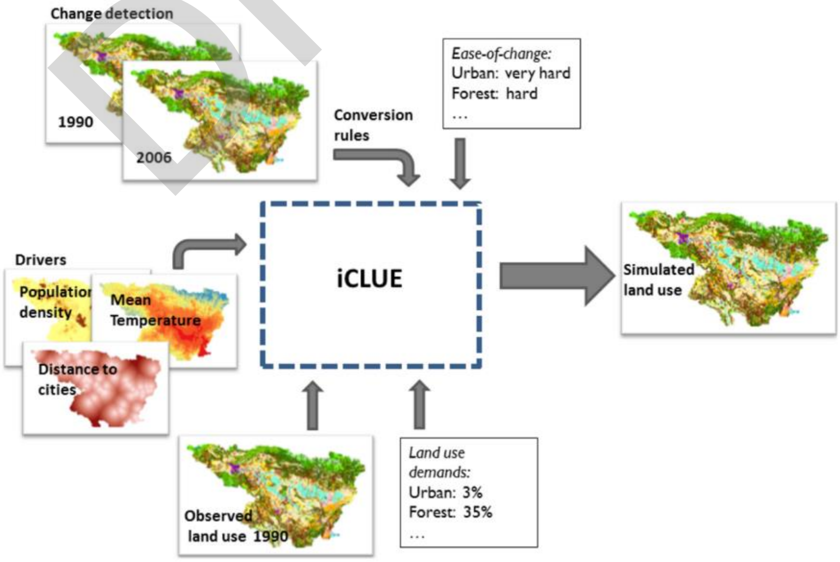



**Figure 1**: iCLUE model inputs (Huber Garcia et. al., 2018).

1. Evaluation of the Factors/Descriptors chosen as drivers regarding the variation in land use
2. Evaluation results of the land use variation (change detection). Historic land use maps
3. An estimation of the ease-of-change value for each of the land uses in each case study area. This value will be used to fine-tune the model outcomes and calculate the probability of an area changing its land use
4. Land use demands
5. A base map from the first point of the time series.

This model will calculate the probability of a land use change occurring in a location using three main variables (see Figure 1):

1. Easy-of-Change
2. Suitability for each type of land use by selecting the most significant drivers using a stepwise regression model to estimate the overall suitability for each land sector
3. Overall land use demands.

The model will use these probabilities to generate land use map projections. Given that this method will be applied to the chosen SSPs, there will ultimately be one map for each scenario. Upon completion these simulations, the next step involves evaluating the quality of the simulations. When examining the results of the CLUEMONDO or iCLUE model, the following aspects must be considered:

1. Persistence simulated correctly (correct rejections)
2. Persistence simulated as change (false alarms)
3. Change simulated as a change to a wrong category (wrong hits)
4. Change simulated correctly (hits)
5. Change simulated as persistence (misses)

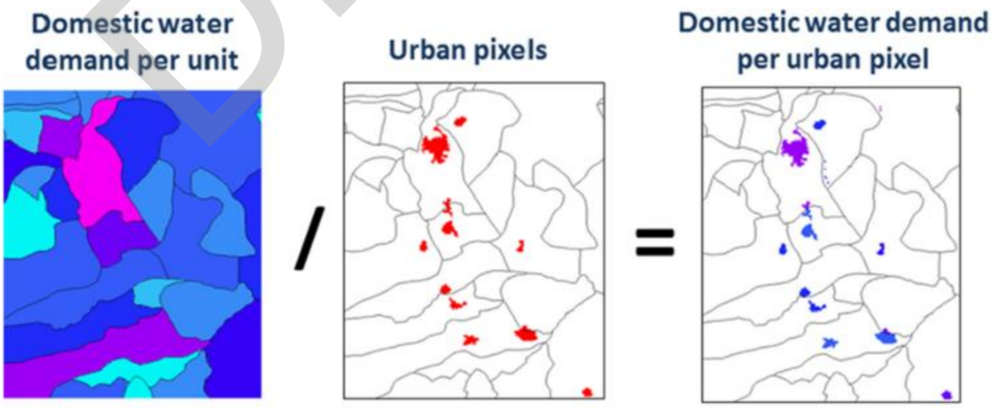



**Figure 2**: iCLUE projected domestic water demands.

Once it has been established that the quality of the simulations is satisfactory, it will be possible to proceed with the use of these projected maps to estimate certain characteristics of interest, such as water demand for drought impact assessments or estimated flood damages. This follows the method used by Huber Garcia et al. (2018). The applied method overlapped the layer of domestic water demand per unit above the projected urban pixels layer, enabling the subsequent estimation of domestic water demand per unit above the projected urban pixels layer, enabling the subsequent estimation of domestic water demand per urban pixel area. This type of estimation is particularly useful for ICARIA's trial assessments since it would allow for the comparison between present and future scenarios. Although the proposed method does not focus on impact assessment, it can be adapted to compare adaptation scenarios in the ICARIA project, establishing tailored socioeconomic projections.

Several indicators can be used to provide relevant information from which to assess the impact of different hazards. They will be linked to the land use information from the iCLUE or CLUEMONDO models coming from the aforementioned authors (Huber García et al., 2018; Verweij et al. 2018), to provide more accurate information to better reflect the different possible outcomes, taking into account the effect of the selected socioeconomic scenarios.

By incorporating the socioeconomic projections derived from the chosen SSPs into future land uses generated by iCLUE or CLUEMONDO models, this method allows for a more comprehensive assessment of the potential impacts of various hazards. The integration of these socioeconomic factors enables a more accurate representation of the diverse outcomes that may arise under different scenarios, accounting for the influence of socioeconomic factors on land use patterns and associated indicators. This approach facilitates the comparison of adaptation scenarios within the ICARIA project by providing tailored socioeconomic projections that can be used in conjunction with the land use projections. By linking the relevant indicators to the land use information from iCLUE or CLUEMONDO models, the method offers a more nuanced understanding of the potential impacts, taking into account the interplay between socioeconomic factors, land use dynamics and the specific hazards under consideration.

**Land Use Change Evaluation Method**

In order to achieve the best results regarding the previous method, a test has been carried out for the case study of the AMB to evaluate the land use cover that has changed during the time series of interest. This step is quite important for the proper evaluation since as discussed earlier, some punctual events may affect the results provided by the collected data after its implementation in the model. After the time series for the land use have been decided, satellite data from the CORINE land cover have been collected https://land.copernicus.eu/en/products/corine-land-cover.

These data have been provided by the IGN, Instituto Geográfico Nacional after adapting it using GIS technologies to a national scale. After that, some transformations have been made to the spatial data with the goal in mind of adapting it to the AMB area of governance. Despite the fact of having only a few temporal series available, land uses were categorized in order to simplify the inputs used for this lab test. The following land use categories were considered:

- Impermeable
- Forestry
- Agriculture and grassland

- Green Area

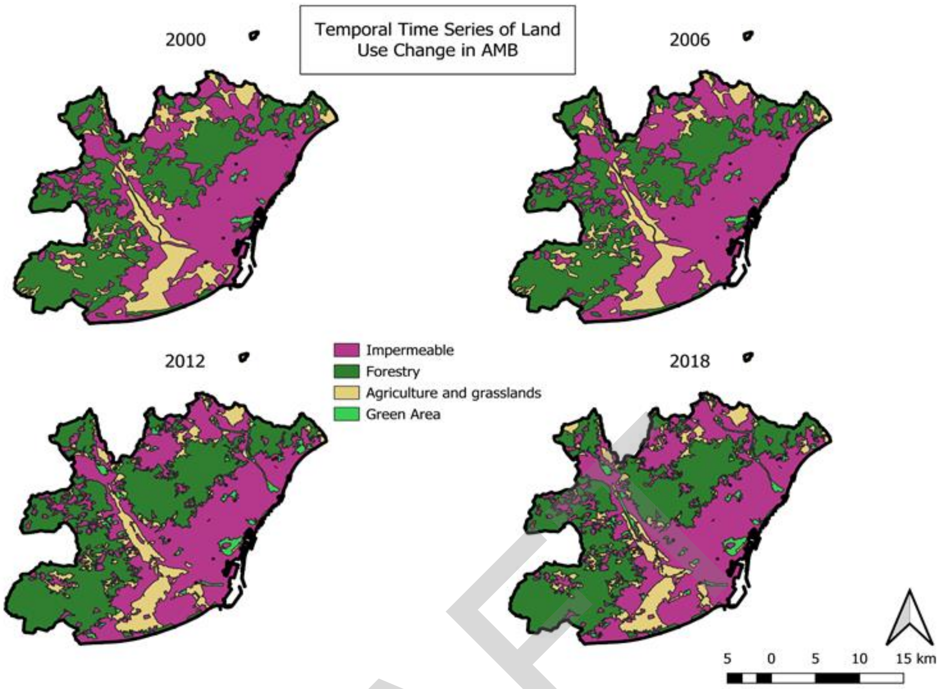



**Figure 3**: Land uses for the different available time series.

### Methodology for Land Cover Change Analysis

**Data preparation:**

1. Perform a dissolve operation on each land cover layer (e.g., 2000 and 2006) based on the unique identifier field "*CODE_S*". This step will create two dissolved layers, where each polygon represents a unique land cover class. ("*CODE_S*" is a field inside of the table attached to the GIS layer provided when downloading CORINE data layers)
2. Calculate the area for each dissolved polygon using the sum of the original polygon areas, grouped by the "*CODE_S*" field.

**Layer Union:**

Union the two dissolved layers from step 1 into a single layer. This new layer will contain polygons representing the intersection of land cover classes between the two time periods.

**Temporal Difference Field:**

Create a new field (e.g., "*2000_2006*") in the unionized layer to indicate whether a polygon has experienced a land cover change between the two time periods. This can be achieved using a conditional statement, as shown below, where WHEN is used in order to make a comparison between the land cover use in year 2000 and 2006 to see if there was any kind of change:

CASE

WHEN “CODE_S_2000” = “CODE_S_2006” THEN 1 (No change)

ELSE 0 (Change)

END

**Area Calculation:**

Calculate the area for each polygon in the unionized layer.
Area Category Field: Create a new field (e.g., "*area_CAT*") to store the area values for polygons that have experienced a land cover change. This can be done using a conditional statement:

CASE

WHEN "2000_2006" = 0 THEN SUM("area_2000", group_by:= "CODE_S_2006")

END

**Final Dissolve:**
Perform a final dissolve operation on the unionized layer, using the "*CODE_S_2006*" and "*area_CAT*" fields as the dissolve criteria. This step will merge polygons with the same land cover class and area category into a single polygon. The resulting layer from this last step will contain polygons representing the land cover classes in 2006, with each polygon carrying information about the area category (i.e., areas that experienced a change or remained unchanged between 2000 and 2006). This methodology allows for the identification and quantification of land cover changes (in Ha, Hectares of land cover) between two time periods, providing valuable information for environmental monitoring, urban planning, and resource management applications.

### 4.1.3 Results of Test A

After gathering the results from the analysis of the land use exchange, the only remaining step is to create the matrix to estimate the ease of change for each type of land use

**Table 4**: Exchange in land use coverage, GDP and population count.

| Hectares of land cover Exchange | | | | | | |
|---|---|---|---|---|---|---|
| | Impermeable | Forestry | Agriculture and Grasslands | Natural Area | GDP | Population |
| **2000-2006** | 2095 | 91 | 389 | 30 | 199.153 | 7.070.810 |
| **2006-2012** | 1102 | 2421 | 960 | 1673 | 201.768 | 7.498.268 |
| **2012-2018** | 814 | 55 | 602 | 223 | 242.434 | 7.591.779 |

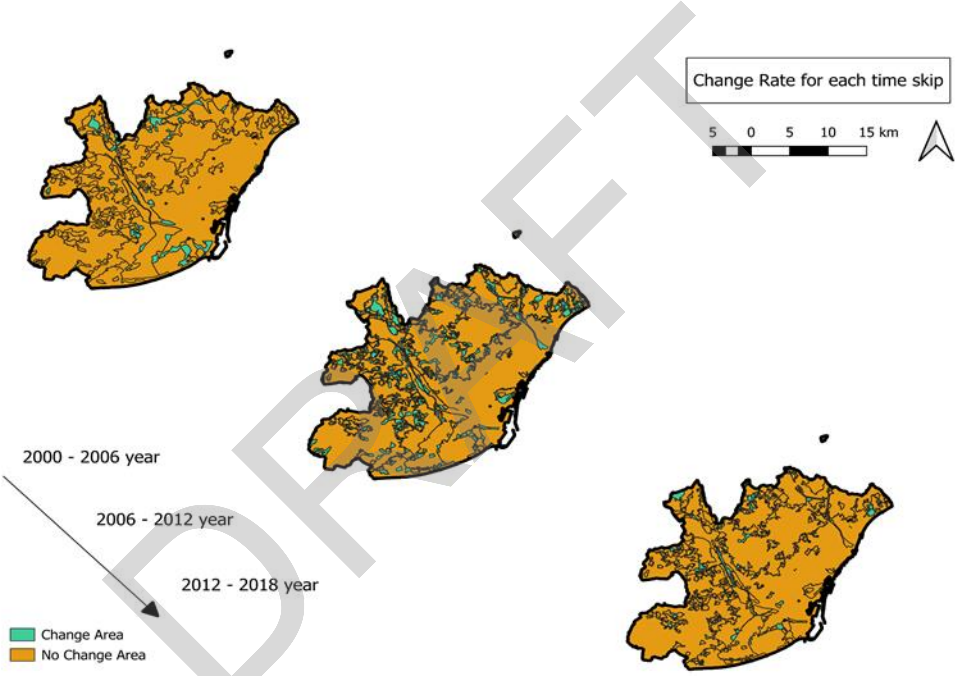




**Figure 4**: Change Rate for the different available time skips.

Figure 4 shows the area where change has happened due to an exchange in land cover use throughout the different time skips. This will allow the user to generate an exchange matrix in order to "*feed*" the iCLUE CLUEMONDO model. These results combined with the proper characterisation of the SSPs + the predictor drivers (such as GDP, population density, etc.) + RCP projections allow iCLUE model to evaluate the future scenarios based on an ease-of-change prediction approach.

As seen in Figure 4 we can also check how one kind of land use can change to another in the whole lab test period (2000 to 2018). Following this process, we can approach the creation of a weights matrix in order to be able to establish the importance of each kind of change, meaning the changes occurring between the land use types studied in lab test A. Taking this into account we have a matrix with a structure of 4 rows vs 4 columns that allow us to check the aforementioned importance of each kind of change. Said types of land use change where:

- Impermeable to Rural and Pastures
- Impermeable to Green Areas
- Forestry to Impermeable
- Forestry to Rural and Pastures
- Forestry to Green Areas
- Rural and Pastures to Impermeable
- Rural and Pastures to Forestry
- Rural and Pastures to Green Areas
- Green Areas to Impermeable
- Green Areas to Forestry
- Green Areas to Rural and Pastures.

It is worth to mention that since the correlation matrix also compares the relation between unchanged areas to a specific year, for each specific time series specified above, those areas are also considered in the list, resulting to a full 4x4 matrix.



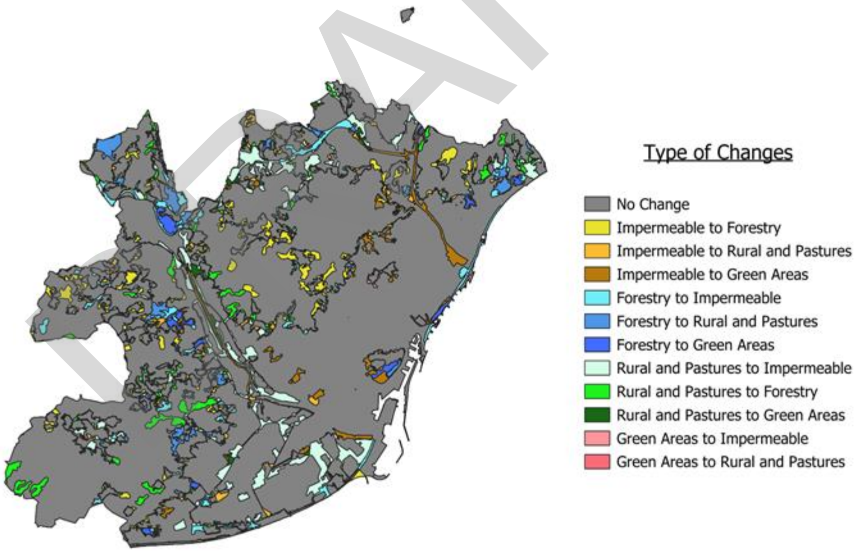



**Figure 5**: Overall change from a specific land use type to another.

In Figure 5, we see the mentioned matrix containing the values for the visualized results in Figure 4. In tables 5 to 8, we see the mentioned matrix containing the values for the visualized results in Figure 5.

If it were of interest, a matrix for each time skip considered during lab test A, was built, in order to get more specific inputs for the prediction model used during the downscaling method. These matrices allow us to have an input for the model in order to be of use as a reference point to train the model, and thus to make further predictions in a more accurate way than with the general land use change case.

This information will be used to make the corresponding predictions regarding land use change in further projections as part of the model.

**Table 5**: Correlation matrix for the weighted exchange between land uses.

| Initial Year=2020 | | | | | |
|---|---|---|---|---|---|
| | | **Impermeable** | **Forest** | **Agriculture and Grasslands** | **Natural Area** |
| Last Year=2018 | **Impermeable** | 0,865 | 0,069 | 0,286 | 0,129 |
| | **Forest** | 0,079 | 0,869 | 0,134 | NULL |
| | **Agriculture and Grasslands** | 0,022 | 0,044 | 0,555 | <0,001 |
| | **Natural Area** | 0,033 | 0,018 | 0,025 | 0,871 |

**Table 6**: Correlation matrix for the weighted exchange between land uses (2000 to 2006).

| Initial Year=2000 | | | | | |
|---|---|---|---|---|---|
| | | **Impermeable** | **Forest** | **Agriculture and Grasslands** | **Natural Area** |
| Last Year=2006 | **Impermeable** | 0,994 | 0,027 | 0,14 | 0,001 |
| | **Forest** | 0,003 | 0,959 | <0,001 | <0,001 |
| | **Agriculture and Grasslands** | 0,001 | 0,014 | 0,859 | NULL |
| | **Natural Area** | 0,001 | <0,001 | 0,001 | 0,999 |



**Table 7**: Correlation matrix for the weighted exchange between land uses (2006 to 2012),

| Initial Year=2006 | | | | | |
|---|---|---|---|---|---|
| | | **Impermeable** | **Forest** | **Agriculture and Grasslands** | **Natural Area** |
| Last Year=2012 | **Impermeable** | 0,857 | 0,046 | 0,162 | 0,137 |
| | **Forest** | 0,08 | 0,902 | 0,18 | 0,003 |
| | **Agriculture and Grasslands** | 0,032 | 0,029 | 0,639 | 0,073 |
| | **Natural Area** | 0,031 | 0,023 | 0,023 | 0,786 |

**Table 8**: Correlation matrix for the weighted exchange between land uses (2012 to 2018).

| Initial Year=2012 | | | | | |
|---|---|---|---|---|---|
| | | **Impermeable** | **Forest** | **Agriculture and Grasslands** | **Natural Area** |
| Last Year=2018 | **Impermeable** | 0,993 | 0,007 | 0,075 | 0,034 |
| | **Forest** | 0,001 | 0,981 | 0,005 | 0 |
| | **Agriculture and Grasslands** | 0,004 | 0,012 | 0,899 | 0,092 |
| | **Natural Area** | 0,002 | <0,001 | 0,021 | 0,874 |

For future tests, it would be advisable to integrate this methodology with the full list of land uses and thus use the whole matrix, although this could bring some computation issues due to the amount of time required for the computation of the model. It could also be of interest to try to choose more/different drivers for the SSPs projections. This method should also be tried in other areas to check how well this model behaves in other case study areas. Regarding the temporal series, it would also be useful to assess the impact of having a bigger amount of time series available for the implementation of this methodology so a fine-tuning of the different time skips could be accomplished. It would also be advisable to test the simulation results under different configuration parameters to test its behavior under different conditions and the impact that significant extraordinary events may have in the execution of said simulation.

## 4.2 Test B: Application of synthetic data generation methods for data gap filling in urban drainage and flooding models

### 4.2.1 Summary and objectives of Test B

Pluvial foods associated with extreme precipitation events are one of the most impactful climate hazards. This situation can be even more critical in urban areas where the extensive impervious areas generate great runoff volumes that can easily exceed the drainage capacity of sewer networks for events above certain return periods. Furthermore, the density of buildings, assets and interconnected services in these areas leads to major economic damages when floods occur (Russo et al., 2020).

Hydrodynamic 1D/2D models stand as the state-of-the-art tool to model and assess the risk associated with pluvial floods in urban areas. These models represent interactions between various components of the urban drainage system (1D domain) and the overland flow paths (2D domain) (Leandro et al., 2009). Nevertheless, such models have large data needs, especially in 1D domain, where it is necessary to characterize all the elements in a sewer network (e.g., manholes, pipes, outfalls, pumping stations, anti-flooding tanks, singular elements). However, often this data is scarce, inaccurate or just unavailable. In the field of extreme events risk assessment, this data gap is a major limitation when doing hazard assessments of pluvial foods (Montalvo et al., 2024). The objective of this test is to develop a criterion to compile a methodology to generate synthetic data of sewer infrastructure for urban areas where information is not existing or not available for researchers.

The test presented is developed within the frame of the 1D/2D model that is currently being developed for the metropolitan area of Barcelona. This model covers a total of 636 km2 including 36 municipalities.



**Table 9**: Test B summary.

| Test B summary | | | |
|---|---|---|---|
| **Methodology** | Methodology to generate synthetic data of sewer networks | **Data-gap** | Physical and topographic data of sewer networks |
| **Hazard** | Pluvial floods | **CS of the test** | AMB |

### 4.2.2. Activities of Test B

Prior to this test there was an extensive data collection effort to gather the geometric and topographic information of as many municipal drainage networks as possible among the 36 municipalities of the AMB. This process was focused on obtaining the data generally generated during the development of municipal drainage master plans. At the end, this information was obtained for a total of 28 out of the total 36 municipalities (see figure below). As reflected in D7.2 (ICARIA, 2024d), this process involved interaction with numerous local stakeholders and the establishment of a collaboration agreement with all the local entities who agreed to share this data in the scope of project ICARIA.

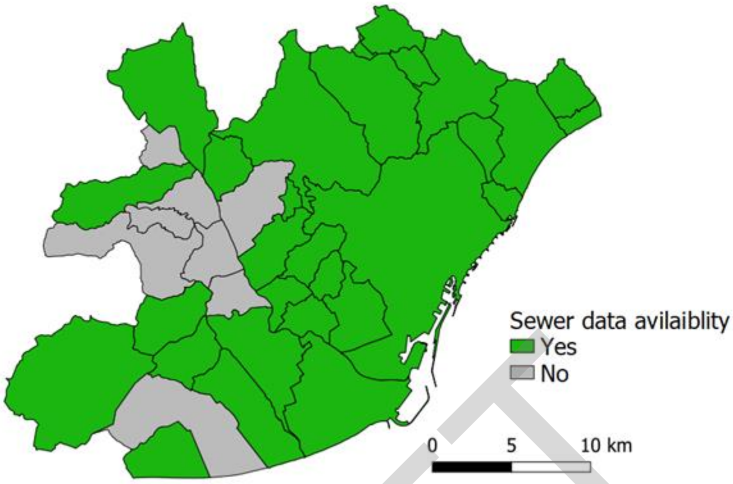



**Figure 6**: Sewer network data availability in the 36 municipalities of the AMB.

The methodology proposed in this test is based on the analyses of the characteristics of the AMB municipalities at two levels. For all of them, an analysis focused on demographic and geographic characteristics has been done with free available data (see Table 9). Additionally, the characteristics of the available municipal sewer networks have been analyzed (see Table 10). This approach allows to characterize both the municipalities and the sewer networks based on common parameters to establish criteria to generate synthetic sewer networks based on similarities among municipalities.

**Table 10**: Analysis of demographic and geographic characteristics of the 36 municipalities in the AMB.

| Data Group | Parameters | Source of Information | Statistical analyses mades |
|---|---|---|---|
| Land use | Total Area | ICGC | Value |
| | Urban Area | ICGC | Value, Percentage |
| | Rural Area | ICGC | Value, Percentage |
| | Land use | ICGC | Percentage among uses |
| | Impervious land | ICGC | Value, percentage; distribution on terrain |
| Population | Inhabitants | IDSCAT | Total inhabitants<br>Distribution in rural and urban areas |
| | Total Population Density | IDSCAT | Value |
| | Urban Population Density | IDSCAT | Value, Percentage |
| | Rural Population Density | IDSCAT | Value, Percentage |
| Street morphology | Street Slope | MDT | Total value, average, variance, Q1, Q3, distribution on terran |
| | Street Length | CNIG | Total value, average, Q1, Q3, distribution on terran |
| | Street Width | CNIG | Total value, average, Q1, Q3, distribution on terran |
| | Basin where the municipality is located | ICGC | Value |

**Table 11**: Analysis of the characteristics of the sewer elements done in the 28 available networks.

| Data group | Parameters | Statistical analyses made |
|---|---|---|
| Pipes | Total number | Value |
| | Total length | Sum |
| | Geometry types | Distribution |
| | Diameter | Distribution, average, variance, Max, Min, Q1, Q3 |
| | Diameter in upper catchment pipes | |
| | Diameter in lower catchment pipes | |
| Manholes | Total number | Value |
| | Depth | Distribution, average, variance, Max, Min, Q1, Q3 |
| | Diameter | |
| | Distance between wells | |
| | Manholes per km of pipes | Value |
| Inlets | Total number | Value |
| | Dimensions | Distribution, average, variance, Max, Min, Q1, Q3, distribution on terran |
| | Distance between wells | |
| | Inlets per manhole | |
| | Inlets per km of pipes (considering pipe slope) | |
| Outfalls | Total number | Value |
| | Geometric dimensions | Distribution, average, variance, Max, Min, Q1, Q3, distribution on terran |

Based on the characteristics of Table 9, all 36 municipalities have been groups based on geographic and demographic similarities as shown in the following figure.

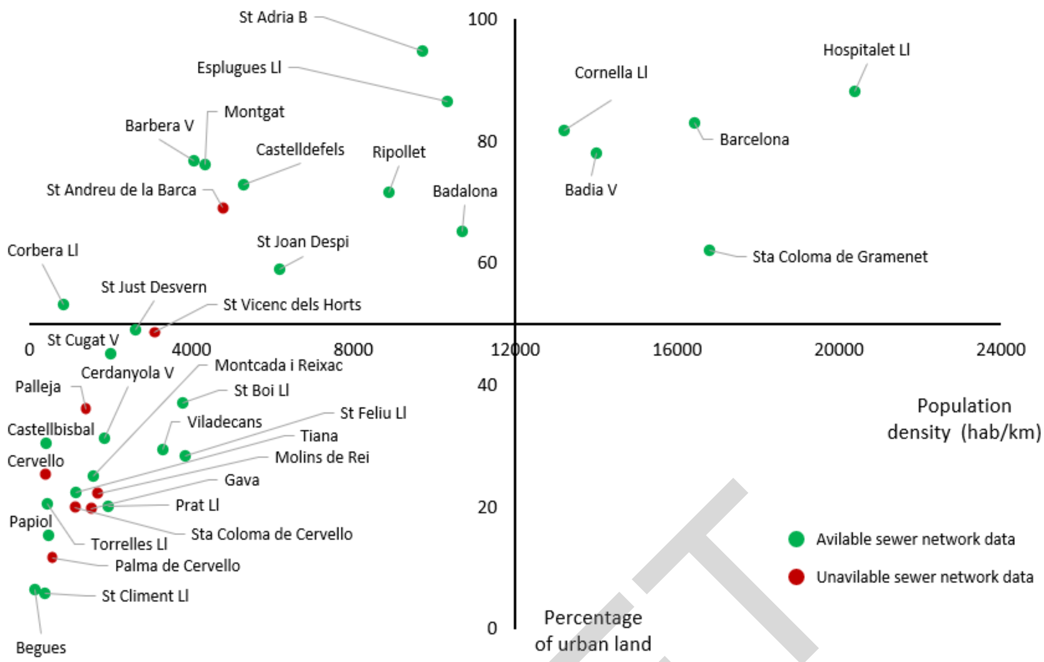



**Figure 7**: Characterization of the 36 municipalities of the AMB based on geographic and demographic parameters.



Considering this correlation, Python scripts have been developed to generate synthetic networks consisting of manholes, pipes, and inlets.

As shown in the table below the test itself was conducted on a subset of 4 municipalities with similar characteristics according to the data presented in Figure 7. They have been split in two different roles in the test as follows:

- Calibration: three municipalities with full data availability used to determine the average value of key parameters to design synthetic networks.
- Validation: a municipality with full data availability that serves to test if the synthetic network generated based on the calibration is similar to the real one.

**Table 12**: Characteristics of the municipalities considered in Test B.

| Municipality | Population density (hab. / km$^2$) | Percentage of urban land | Sewer data availability | Role in the test |
|---|---|---|---|---|
| Montgat | 4.350 | 76 | Yes | Calibration |
| Barberà del Vallès | 4.067 | 76 | Yes | Calibration |
| Castelldefels | 5.281 | 73 | Yes | Calibration |
| St. Joan Despí | 6.195 | 60 | Yes | Validation |

The following tables show the statistics of the relevant sewer network parameters extracted from the calibration municipalities. Based on these results, an average value of all the parameters that have been considered relevant to generate a synthetic network have been calculated.

**Table 13**: Key characteristic parameters of the sewer network of the Calibration municipalities and values defined for the generation of synthetic networks.

| Structural element | Parameter | Municipality | | | |
|---|---|---|---|---|---|
| | | Montgat | Barberà del Vallès | Castelldefels | Synthetic networks |
| Pipes | Number | 1544 | 3264 | 6326 | n.v. |
| | Distance (km) | 47.33 | 113.22 | 239.34 | n.v. |
| | Pipe length / Street length | 1.065 | 1.095 | 1.104 | 1 |
| Manholes | Number | 1504 | 2634 | 4739 | n.v. |
| | Units per km of pipe | 32 | 23 | 20 | 25 |
| | Average separation | 32 | 43 | 51 | 30 |
| Inlets | Number | 1007 | 3396 | 5595 | n.v. |
| | Units per km of pipe | 21.3 | 30 | 23.37 | 24 |
| | Units per manhole | 0.69 | 1.28 | 1.18 | 1.3 |

**Table 14**: Basic statistics of some characteristic parameters of the sewer network of the Calibration municipalities and values defined for the generation of synthetic networks.

| Parameter | Municipality | AVG | St Dev | Max | Min | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Pipe length (m) | Montgat | 30.6 | 26.43 | 262.5 | 1 | 14 | 40.5 |
| | Barberà del Vallès | 34 | 27 | 463 | 0.5 | 16.6 | 45.5 |
| | Castelldefels | 37.8 | 48.14 | 1833 | 1.03 | 22.59 | 44.21 |
| | Synthetic networks | 30 | n.v. | 30 | 0.5 | n.v. | n.v. |
| Pipe diameter (mm) | Montgat | 700 | 760 | 6000 | 100 | 300 | 645 |
| | Barberà del Vallès | 560 | 480 | 4500 | 60 | 400 | 600 |
| | Castelldefels | 450 | 2209 | 8000 | 80 | 300 | 500 |
| | Synthetic networks | 570 | n.v. | 6000 | 200 | n.v. | n.v. |
| Manhole depth (m) | Montgat | 0.74 | 0.82 | 6.34 | 0.01 | 0.3 | 0.75 |
| | Barberà del Vallès | 3.2 | 1.13 | 10.9 | 0 | 1.68 | 2.7 |
| | Castelldefels | 1.6 | 1.01 | 43 | 0.3 | 1.19 | 1.92 |
| | Synthetic networks | 2 | n.v. | 2 | 2 | n.v. | n.v. |



The main characteristic parameters defined to generate synthetic networks can be summarized as follows:

- The correlation between pipe total distance and street total distance in the municipality should be close to one.
- The number of manholes should keep a correlation close to 25 manholes per km of pipe and have an average distance of around 30 meters.
- Similarly, the number of inlets should be close to 24 elements per km of pipe.
- The average pipe length should be 30 meters. No pipes longer than that will be considered in the generated networks.
- The depth of manholes is set at a fixed value of 2 meters.

Another relevant aspect to characterize sewer networks in the distribution of pipe diameters in the whole network. The graphs below depict this information of the investigated municipalities.

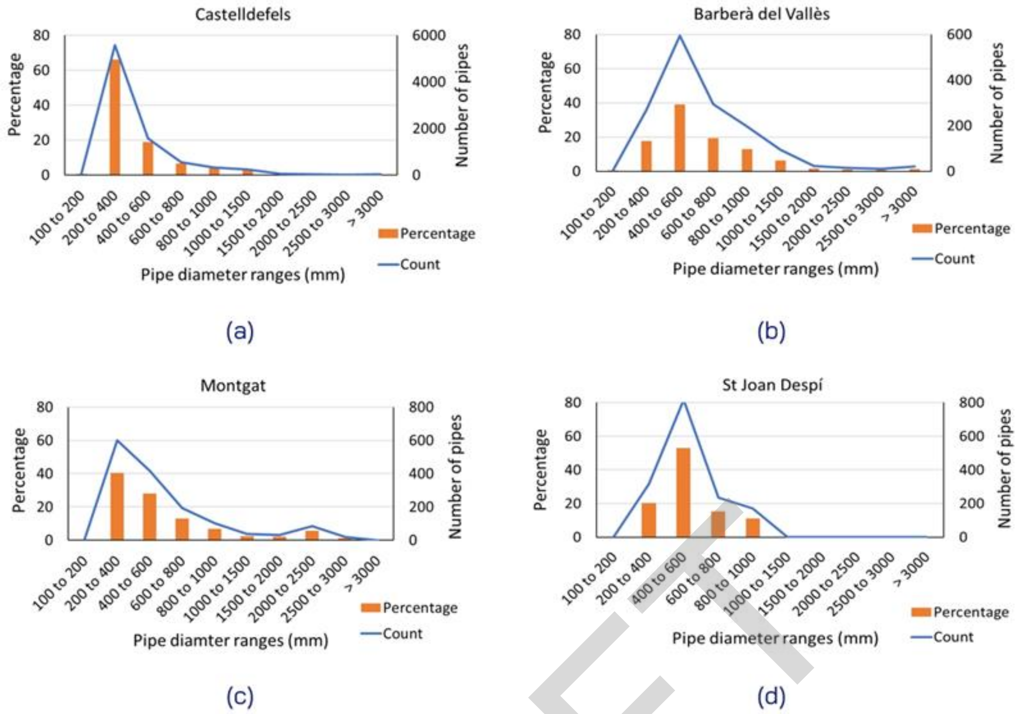



**Figure 8**: Distribution of pipe diameters in the municipal sewer networks of (a) Castelldefels, (b) Barberà del Vallès, (c) Montgat and (d) St Joan Despí.

It can It can be observed that the majority of pipes lie in the range between 200 to 600 mm of diameter, representing the secondary sewer network. A reduced percentage corresponds to the primary network, with pipes between 600 and 1000 mm. The larger pipes correspond to the main collectors that convey water from the primary and the secondary network in a reduced number of axes.

Apart from the above-mentioned criteria, some other assumptions have been made regarding the structural and geometric characteristics of the synthetic sewers:

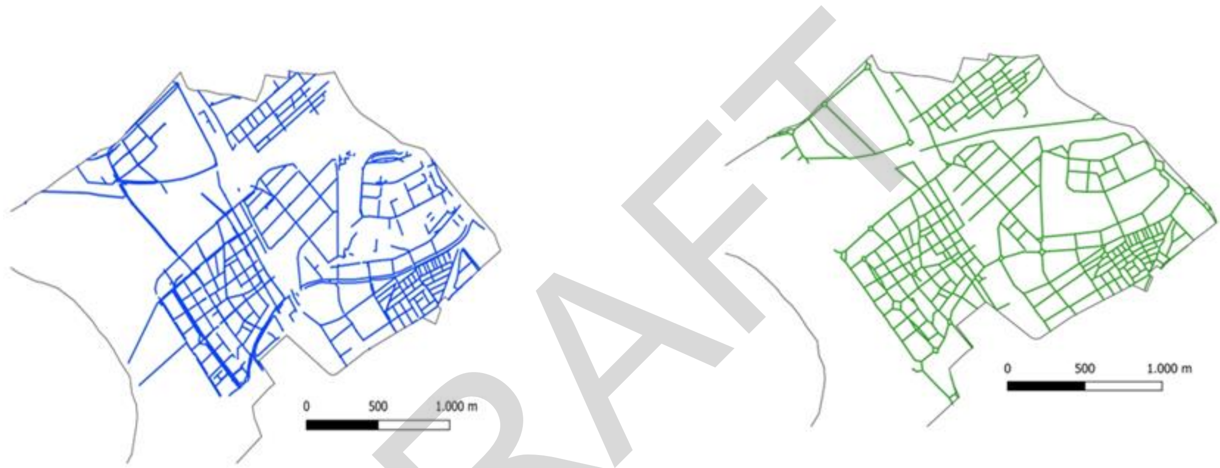
- All pipes are alienated with pawed streets
- One manhole is located in each pipe junction
- The upstream and downstream pipes reaching a manhole are connected to its lowermost point
- The spacing between manholes is more or less regular in the whole municipality
- The spacing between inlets is more or less regular in the whole municipality but it is conditioned by the street slope
- The inlet typology is the same in the whole municipality.

### 4.3.3 Results of Test B

Based on the criteria defined above, a set of GIS processes and python scripts have been applied to generate a synthetic sewer network for the municipality of Sant Joan Despí, where data of the actual infrastructure is available. This exercise serves to validate if the assumptions made allow to generate a realistic reproduction of a real network.

Figure 9 depicts the location of the sewer pipes both in the actual and in the synthetic network of Sant Joan Despí. At a graphic level, it can be observed that they show a fairly similar layout in the whole municipality. This fact indicates the validity of the assumption that "*All pipes are alienated with paved streets*". However, errors can be observed. Most of them are related to major streets where the synthetic network indicates one single pipe while in reality there are two or three parallel ones. This mismatch can potentially lead to under estimations of the number of pipes, mainly in the primary network.

A more detailed view of both networks is provided in Figure 10. It can be seen that, apart from a close representation of pipes, the distribution of manholes along the sewer network also shows a good degree of similarity. Specially in points with intersections of three or more pipes and along longer continuous pipes.




(a) (b)

**Figure 9**: Layout of the pipes in Sant Joan Despí according to (a) a map of the actual sewer system and (b) a synthetic network.

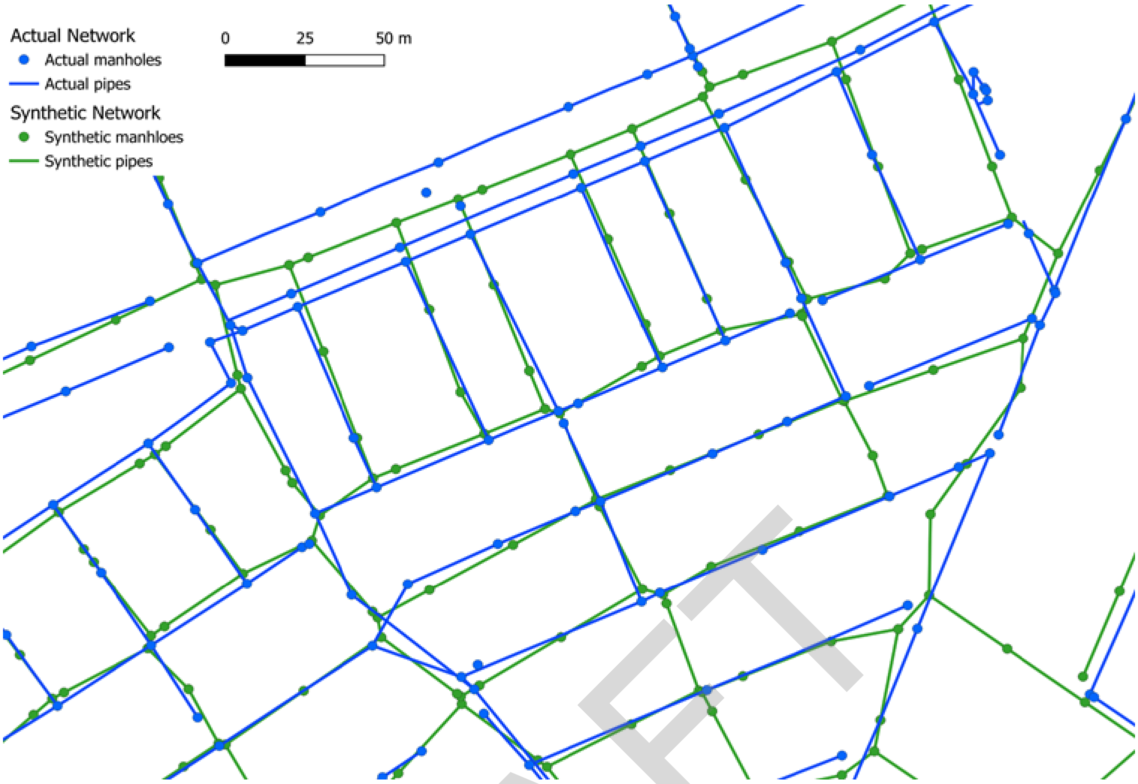



**Figure 10**: Detailed view of the synthetic and the actual network.

The following table summarized the main characteristic parameters of both networks. It can be observed that the synthetic network has generated an accurate number of pipes and manholes in comparison with the reference actual network. This fact provides consistency to this data gap filling method. However, it can also be noticed that the total length of pipes is 25% lower in the generated data. As indicated in earlier paragraphs, the main reason behind this underestimation is the assumption that only one pipe is located under each street of the municipality, hence the existence of parallel tubes is neglected.

As for inlets, their total number has been determined based on the ratio of 1.3 inlets per manhole extracted from the calibration municipalities. However, the actual network data shows that in the case of Sant Joan Despí, this ratio is 1.6 (a 23% higher). Consequently, there is a significant difference in the number of inlets considered in each case.

**Table 15**: Comparison of the key characteristic parameters of the actual and the synthetic sewer network of Sant Joan Despí.

| Element | Parameter | Actual network | Synthetic network |
|---|---|---|---|
| Pipes | Total number | 2004 | 2097 |
| | Total length (m) | 66849 | 49847 |
| | Pipe length / Street length | 1.10 | 0.82 |
| | Average pipe length (m) | 33 | 23.77 |
| Manholes | Total number | 1985 | 1907 |
| | Units per km of pipe | 30 | 38 |
| Inlets | Total number | 3167 | 2479 |
| | Units per km of pipe | 47 | 49 |
| | Units per manhole | 1.6 | 1.3 |



In summary, the data gap filling methodology to generate synthetic sewer network data has proved to be able to accurately replicate existing simple drainage infrastructure, considering only manholes, pipes and inlets. However, some of the assumptions involved lead to an underestimation of the total length of pipes, which can lead to an underestimation of the drainage capacity of the infrastructure.

Further work will be developed to amend this limitation by identifying the areas of the investigated area where it is likely to find parallel pipes.

Another crucial aspect to generate reliable synthetic networks is the diameter assigned to each pipe. This parameter is essential as it determines to a good extent the amount of water that can be conveyed in each case (together with other relevant parameters such as the slope and the roughness coefficient). As depicted in Figure 8 (c) most pipes in Sant Joan Despí lie in the range between 200 to 600 mm that, in a municipality with a degree of imperviousness and population density as this one, can be considered as a secondary network. The approximately 600 pipes with diameters of 600 to 1000 mm are then considered as the primary network. In order to adequately identify both networks and assign realistic diameters to pipes, the following methodology is suggested.

The Shreve methodology (Strahler, 1964) is a stream ordering system used in hydrology to classify and analyze the hierarchy of streams in a watershed. It assigns a magnitude to each segment based on the number of upstream segments contributing to it. In this system, each segment of the stream network is initially assigned a magnitude of 1. When two segments merge, their magnitudes reflect the total number of upstream segments contributing flow to any given segment. A basic example is depicted in Figure 11.

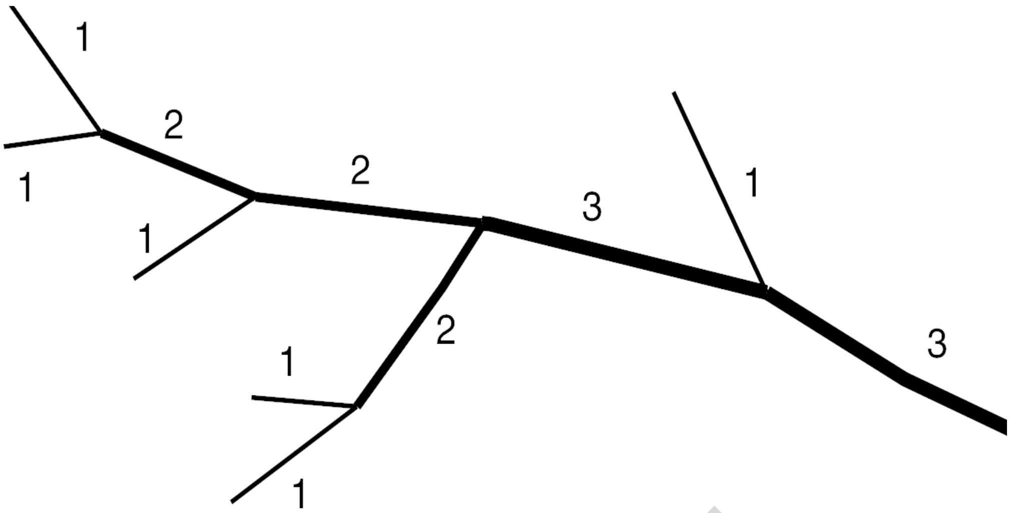



**Figure 11**: Classification of the order of pipes in a basic sewer network following the Shreve classification.

If applied to an urban environment, the Shreve method can give information to classify the magnitude of the preferential flow pathways established by superficial flow. This means that streets with a higher order naturally convey a larger quantity of water. Considering that sewer pipes are located under paved streets, this method can also be applied to sewer networks to analyze the flow of wastewater through pipes.

If the magnitude assigned to a superficla water course in a street is high, meaning that it conveys a large amount of water, presumably, the pipe located below that street will have a large diameter. Therefore, the magnitudes assigned to a water course help in understanding the load distribution within the network, where segments with higher magnitudes indicate higher combined flows and, ultimately, can help to define a criterion to assign a diameter value to all pipes in the network. Figure 12 shows a classification of the superficial flow pathways in the Sant Joan Despí overlayed with the synthetic network generated. The following table suggests a relationship between the order of the superficial pathways and the diameter to be assigned to pipes.

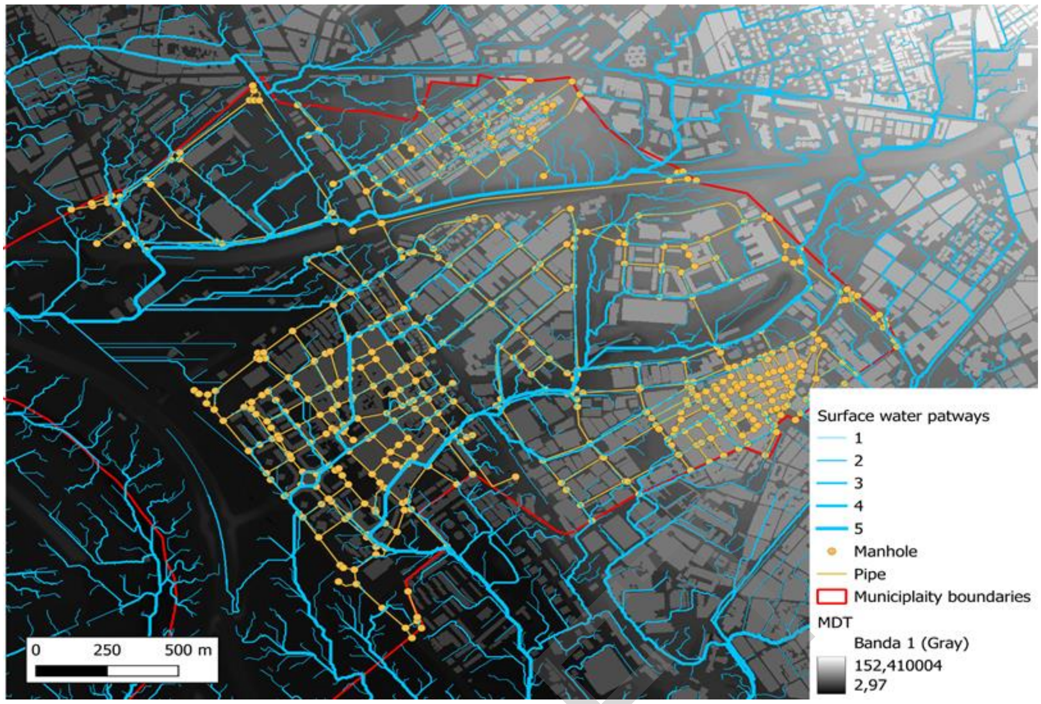



**Figure 12**: Shreve classification of the superficial water courses in Sant Joan Despí together with the synthetic sewer network generated.

**Table 16**: Proposed relationship between the Shreve classification value and the pipe diameter.

| Shreve classification value | Pipe diameter (mm) |
|---|---|
| 1 | 200 |
| 2 | 400 |
| 3 | 600 |
| 4 | 800 |
| 5 | >1000 |

The upcoming work in WP4 of this project will allow the improvement and further refinement of the methodology presented in this section.

## 4.3 Test C: Impacts of windstorm and fallen trees on road network of rural/peri-urban areas

### 4.3.1 Summary and objectives of Test B

Within this test, the data availability for the ICARIA multi-hazard methodology (ICARIA, 2023a) is assessed, with a special focus on the Salzburg region. Within the deliverable the general approach of the elementary brick model was presented, which also clearly shows the areas where data is needed: hazard, exposure, (dynamic) vulnerability. Based on the data provided, an impact assessment model can be applied and the damage associated with a single or multi-hazard event can be estimated.

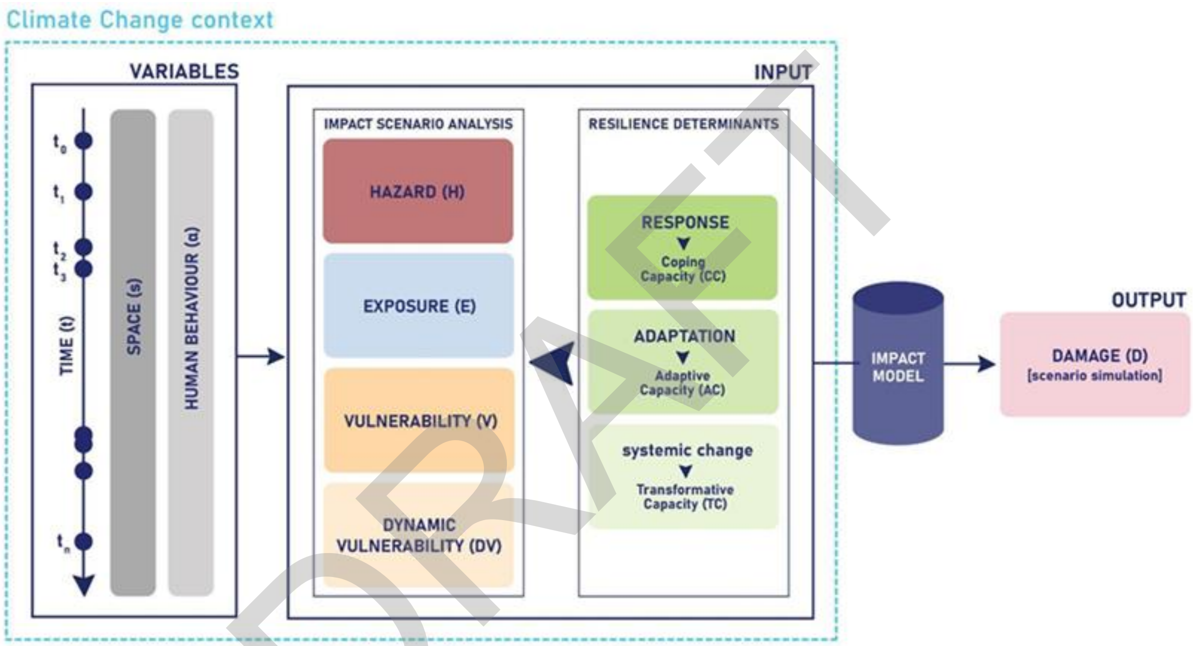



**Figure 13**: Scheme for climate change context within the ICARIA project.



#### 4.3.1.1 (General) Background on Salzburg Trial

The test focuses on the rural areas of the Federal State of Salzburg (Land Salzburg[1]; SLZ), which are characterized by (steep) mountains, streams and relatively small settlements. Over the past 20 years, floods have caused enormous financial damage and psychological stress to the inhabitants. In addition, storms, combined with changing climatic conditions that weaken the forest, have led to significant forest loss. Although local stakeholders (forest owners, forest managers, etc.) are aware of the increasing need to better adapt to the local impacts of climate change, the direct and obvious evidence of the impact of adaptation measures (either in terms of cost or reduction of damage) is still not very visible, if at all. This is largely due to the scarce availability of data on damages that relate the two, i.e., that can be used to provide such evidence.

[1] https://en.wikipedia.org/wiki/Salzburg_(federal_state)

Within ICARIA, high-resolution hazard data have been produced using two different downscaling techniques (see above and D1.2 (ICARIA, 2024a)). As a result, we have state of the art hazard data, e.g., flood maps/wind intensities, which are used as input data for the impact assessment mode. However, information on past events is crucial for the quantitative estimation of damages. Although information on the occurrence of past events is available, we lack information on how much damage (physical, monetary) was caused to assets (e.g., houses, electricity infrastructure) during specific events in the past. It is therefore difficult to link the observed intensities (which we know from observations and model data) to the associated monetary losses. Linking intensities to observed losses would allow us to estimate vulnerability curves for the assets being assessed and is therefore critical information.

#### 4.3.1.2 Test C Objectives

The lab test aims to identify and address the data gaps related to the implementation of the Multi-Hazard Impact Assessment trial in the SLZ region. The data gaps can occur at the level of hazard, exposure, vulnerability and impact. Following the challenges described for floods and high winds associated with storms (in the last subsection), the potential data that would be suitable for linking event intensities to observed losses for these two event types have been identified. These data, or their absence (i.e., data gaps), are listed in the Annex of this document for Lab test C.

The aim of this task is to test the relevant tools and methods on some baseline data to ensure that they are robust and ready for implementation in the subsequent steps of the process. Building on the work done in Task 1.3 (ICARIA, 2024b), one data gap of high relevance to the project and the study region of Salzburg has been selected. This data gap focuses on trees and the effects that strong winds can have on them (e.g., damage and breakage, complete uprooting). Such trees can directly disrupt infrastructure, such as power and transport networks, as well as cause bridge clogging during (subsequent) floods by accumulating woody debris. A high-level summary of the data gap (DG-SLZ-Trees) is presented in Table 8. It highlights the primary data gap(s) to be filled. For each tree the following characteristics are considered:

1. Tree type (i.e., which tree it is, as different tree types have different resilience features)
2. Location (latitude, longitude)
3. Their absolute and relative numbers
4. Trees within the define distance from critical infrastructure (i.e., road network)
5. Number and location of damaged trees.

**Table 17**: Table C summary.

| Test C summary | | | |
|---|---|---|---|
| **Methodology** | Combination of exploiting old datasets, GIS-expertise, and data analytics experience | **Data-gap(s)** | Trees:<br>• Type<br>• Number<br>• Geo-distribution<br>• Number of fallen/broken ones |
| **Hazard** | Extreme wind / Storm | **CSF of the test** | SLZ |

### 4.3.2 Activities of Test C

In the following, a distinction has been done between the first steps in the methodology/approach that are on a general level (identification, confirmation and deep dive search; steps 1-2 below) and the steps that are directly related to solving data gaps (from step 3).

1. **Identification of the data gap**, and a first-level confirmation by those in need of the data (e.g., stakeholders, experts on the field/climate model) stating a lack of data and a need for a more thorough search on various online and offline platforms.
2. **Deep dive search** for the data incorporates:
   i. European Commission, Europe-level, regional, national (i.e., Austrian) and local data sources and web-portals (e.g., tree and biomass registries/cadastres).
   ii. Communication with relevant institutions – from universities, research institutions to entities managing cadastres.
   iii. Scientific publications with potentially relevant, accessible, and open data.
   iv. Online data science/analysis portals focusing on competitions and general data science education (e.g., Kaggle, 2024).

In case that these first steps are not solving the data gap, i.e., locating, accessing, and integrating a suitable dataset, there is a need to apply methodologies that could indirectly resolve the issue.

**Results for the SLZ trials on the steps 1-2:**

It is expected to find suitable and appropriate datasets to fill the data gap(s), taking into account the wealth of technologies available today that can produce such data (e.g., Earth observation, in-situ monitoring, terrestrial laser scanning). However, this potential availability is hampered by the fact that sensor resolutions (spatial, temporal) are limited, outdated and/or the data produced are commercial or not available as open data. This is what it is possible to conclude after visiting several international and national data portals (e.g., EC Copernicus, 2024), (INSPIRE Geoportal, 2024), (SAGIS, 2024), etc.; see the Cookbook of D1.3). In addition, attempts have been made to contact relevant institutes, experts and data owners directly, but these have either not been answered or have led to dead ends. It is therefore necessary to investigate a methodology to fill the data gap using alternative methods. Several are listed in the Cookbook of the mentioned ICARIA deliverable (D1.3 (ICARIAc, 2024)), but after a closer look at these methods it is concluded that they do not meet the objective of the Salzburg process, at least for the selected data gap DG-SLZ trees.

**Methodology Step-by-Step: solving for DG-SLZ-Trees data gap**

Previous experience on data analysis and data processing tools has been used to try to fill the data gaps, which requires creative and intelligent approaches. However, most of these approaches can and will introduce a degree of uncertainty, so it is necessary to not only be aware of this when using the resulting datasets, but also try to quantify the level of uncertainty. The steps are described below.

The following methodology/approach specifically addresses the data gaps on tress for the SLZ region:

3. **An online portal (Waldinventur, 2024) has been found with the map service showing the distribution of trees and tree species and tree types in Austria**, including the Land of Salzburg. The owner of the portal did not respond to the project request to share the source of the data. The owner of the portal is the same person contacted before without knowing about the portal, but who did not respond or could not share the data with the project consortium.
    a. Data could not be extracted directly from the portal. The portal provided table view as well, however, with only high-level information and statistics, not quite what is needed to fill the test data gap.
4. **An INSPIRE dataset[2]** with tree distribution and tree categories was found, but it is from an earlier date (December 2009), so it may not be accurate and may even be quite outdated. Furthermore, tree categories are not identified (i.e., they are only numbered from 1 to 5, but there is no indication of which tree type is which number).
5. **To sources have been combined to identify the categories using available tools (e.g., QGIS), and extract the location of each tree** (or raster pixel that has assigned a category to it):
    a. The distribution of trees on the online portal, provides the different tree categories (e.g., oak, spruce), and compare it with the INSPIRE database. Through the comparison, it is possible to assign the correct category to the INSPIRE dataset and obtain an "*updated*" INSPIRE dataset (see Figure 14).
6. GDAL (Rouault et al., 2024) and related libraries to extract the location (Lat, Long.) and tree type from the "*updated*" INSPIRE dataset has been used: These include a process combining several steps using open sources shapefiles:
    a. Prepare layers (Land Salzburg, 2022):
        i. Original/target layer/GeoTIFF with all the trees for the whole Austria)
        ii. Masking layer taken from the GADM database providing the shapefiles for different administrative levels (Figure 14).
    b. Clip target raster using a mask/polygon (Tool: "*Clip raster by mask layer*"



[2] https://inspire.lfrz.gv.at/000605/ds/baumart_tiled.tif

c. Reproject from meters to decimal coordinates using latitude and longitude, with CRS – WGS84 / EPSG:4326 (Tool: "*Reproject layer*").
d. Export points from the layer/GeoTIFF raster to .csv format having latitude, longitude and type for every pixel/tree (Tool: "*gdal2XYZ*").
e. Exclude unwanted raster pixels. We only keep the data (pixels) with trees, so all other pixels are excluded. In test data, these unwanted pixels have a value of 0. This simplifies the data and optimizes the processing time. This task has been performed using R language (The R Project, 2024) because of its flexible approach. The outputs are given in a *.csv* format (see Figure 15).
f. Select only trees within a distance from roads: only trees that could have an impact on the road network (blocking, damage, etc.) in the event of a storm have been considered. It was assumed that other trees further away are less likely to have an impact due to distance. Open StreetMap (OSM) dataset for roads for the province of Salzburg have been imported and a buffer zone of 80 meters along the road lines (as a line has no width, 80 meters would mean about 10-20 meters of the road itself and then 20-30 meters on each side) have been created. This number can be changed, but it was considered as realistic for the test. This newly created road buffer has been used to select only trees within the buffer and this gives the final data sets. Example in Figure 15 for the Salzburg district of Tamsweg. (Tools: "clip", "*buffer*", "*clip raster by mask layer*", "gdal2xyz").



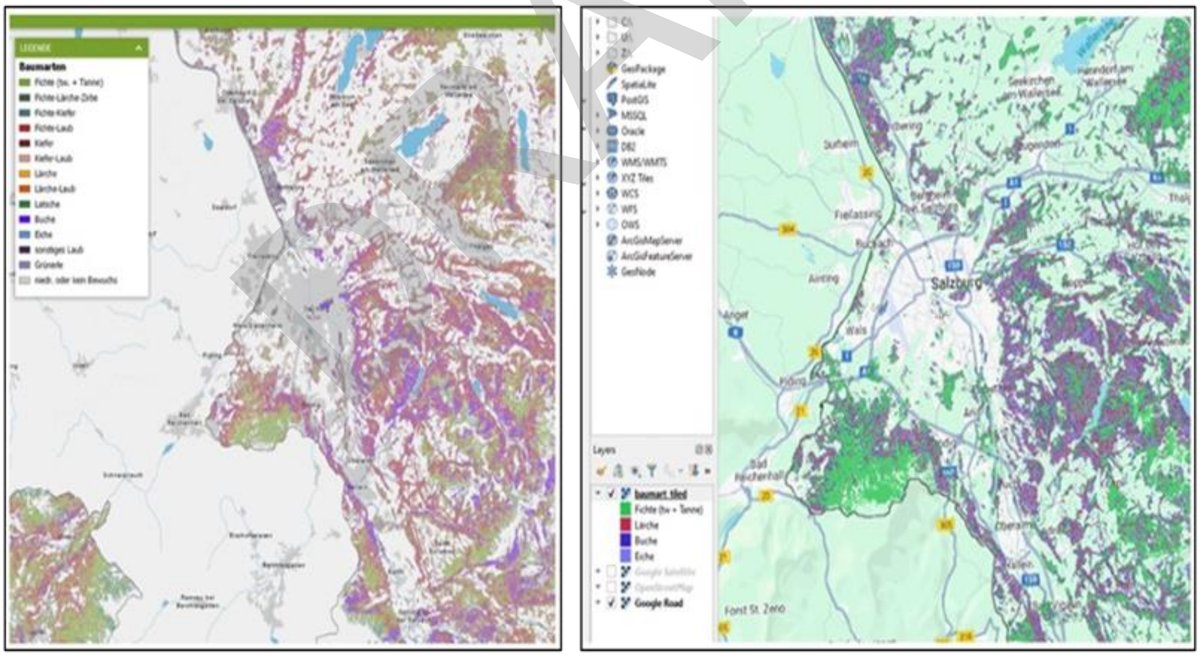


**Figure 14**: An online portal providing a map view of the up-to-date tree distribution and tree type. Using the categories from the left map, we can manually assign tree types to the INSPIRE dataset and create a map as shown here on the right.

General note on the process: the administrative level 1, which is the shape files of the Austrian Federal States was the first option. However, due to the high number of points (pixels), the extraction of the whole province of Salzburg took a very long time (or required a very long time), the administrative level 2, which represents the districts of the province of Salzburg was used.

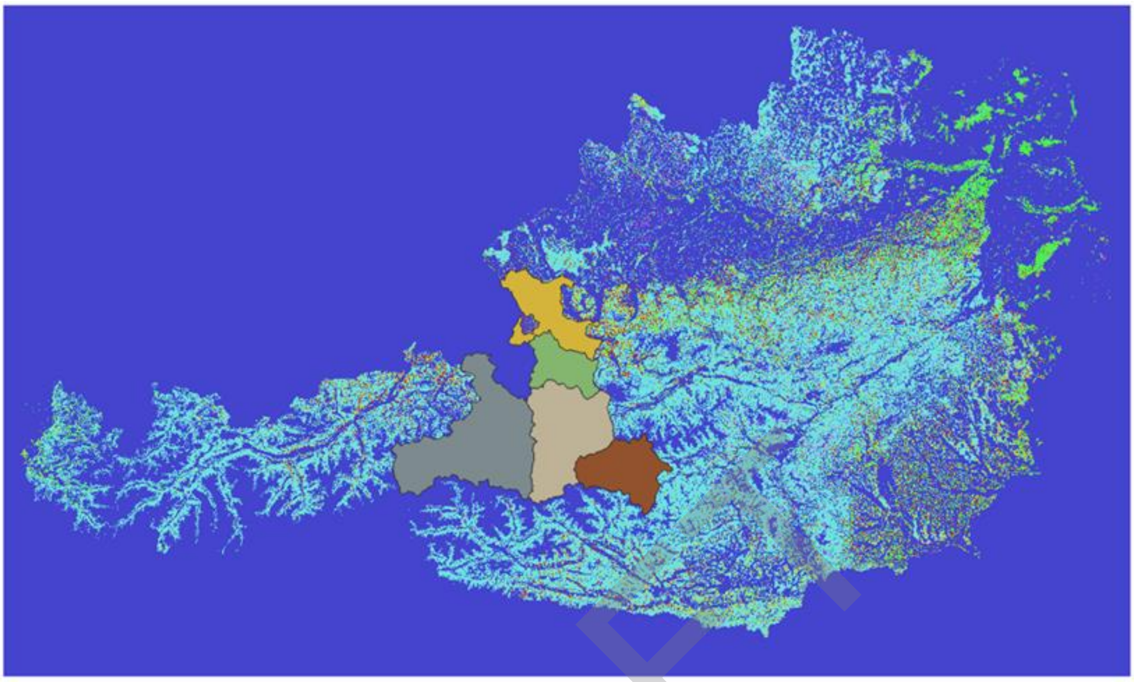


**Figure 15**: Trees in Austria from the INSPIRE dataset and overlay with shapefiles of 6 districts of the federal state of Salzburg.



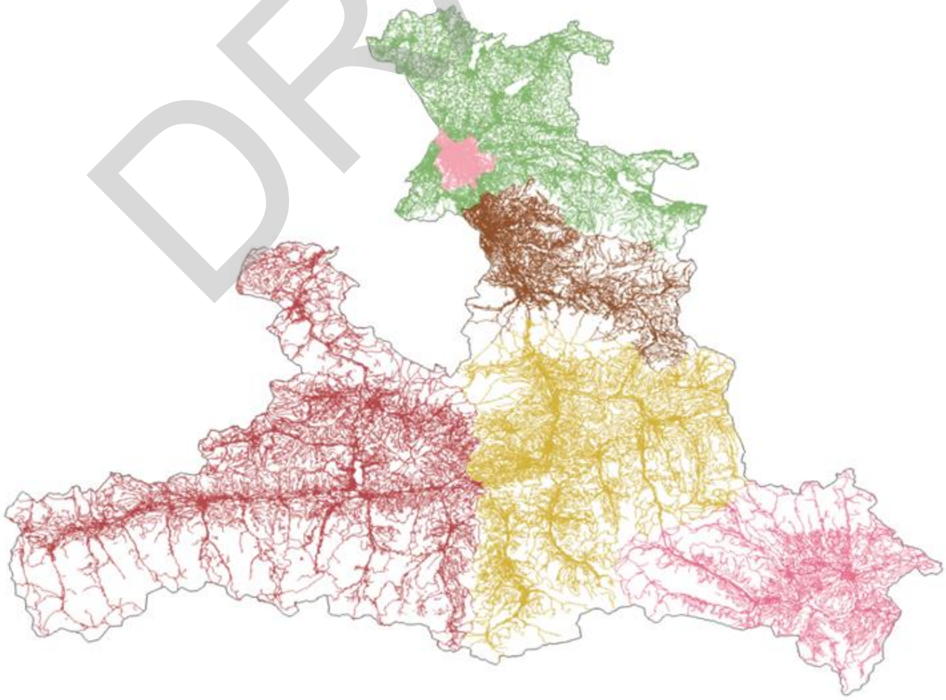


**Figure 16**: OSM Road network for the 6 districts of the Federal State of Salzburg. The coloring is only to highlight the road coverage for each of the 6 districts.

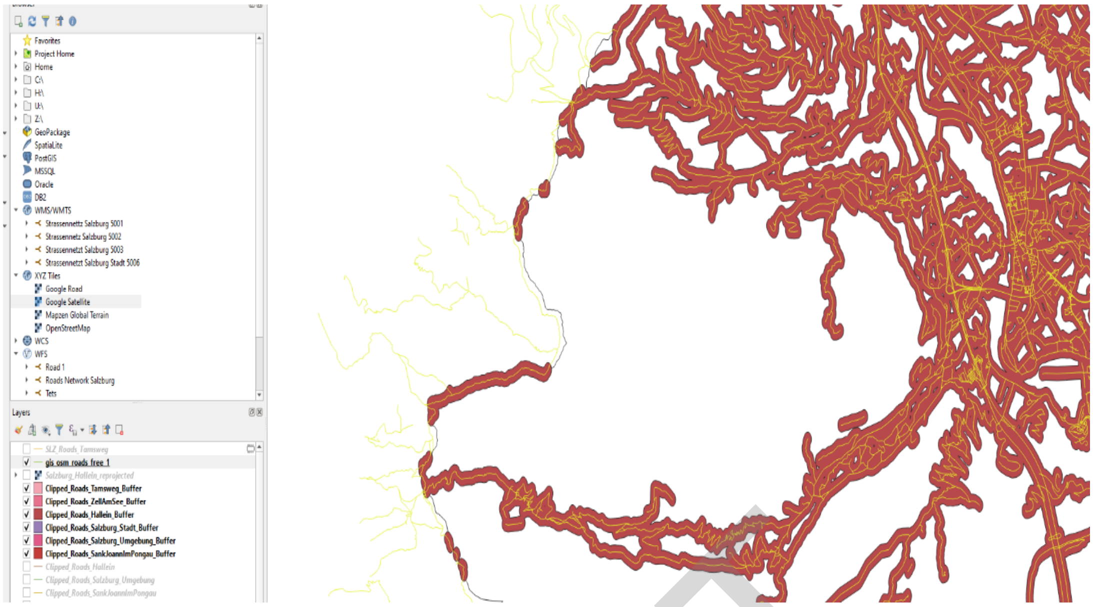


**Figure 17**: A part of the Hallein district road network. Roads are yellow (geometrical) lines provided by the OSM dataset, while the red coloring is the buffer zone of 80 meters across, was used to select the trees.



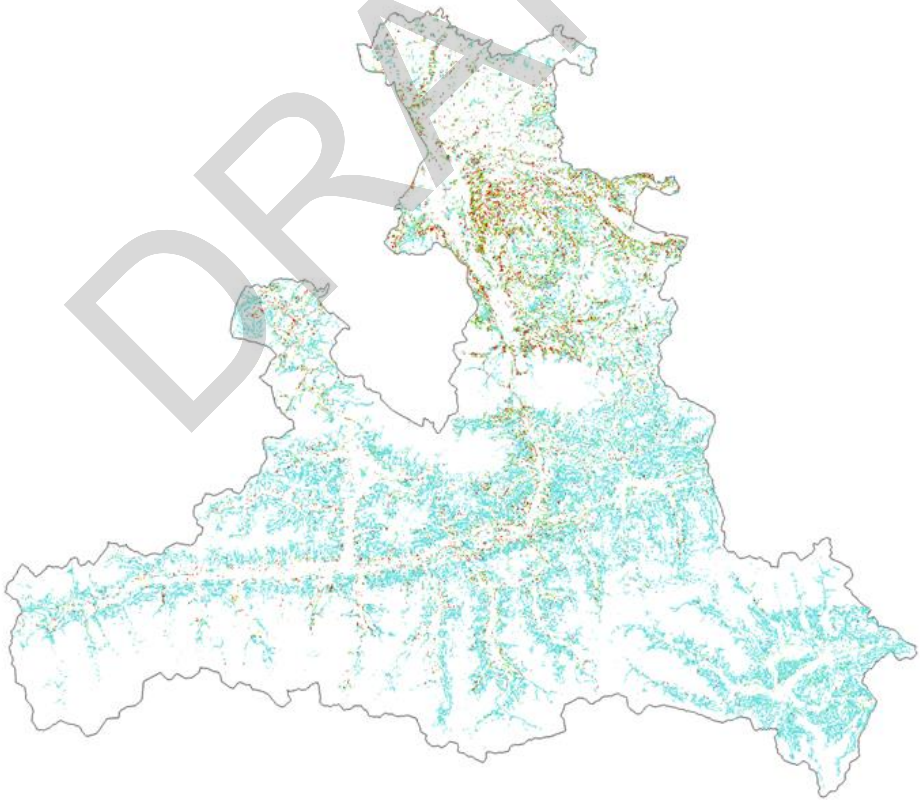


**Figure 18**: The trees for the Federal State of Salzburg after applying the road network buffer zone.

### 4.3.3 Results of Test C

The output of the steps described and processed in 4.3.1 are records with tree attributes. For each district of Salzburg, a .csv file is created with the location and species of the tree (Figure 18). Furthermore, these are only trees that are primarily relevant in the context of the impact on the transport network (i.e., the road network), i.e., those within a buffer around the roads (*Salzburg_Hallein.csv*, *Salzburg_JohannImPongau.csv*, *Salzburg_Salzburg_Umgebung.csv*, *Salzburg_ZellAmSee.csv*, *Salzburg_Tamsweg.csv and Salzburg_Stadt.csv*). The output could also be a GeoTIFF file or any other file format for storing georeferenced information. Additional transformation steps should then be applied.

```
Long;Lat;TreeType
13,18430888;47,76790589;Fichte
13,18976443;47,76790589;Fichte
13,18158111;47,76756492;Fichte
13,18192208;47,76756492;Fichte
13,18226305;47,76756492;Fichte
13,18260402;47,76756492;Buche
13,18294499;47,76756492;Fichte
13,18328597;47,76756492;Fichte
13,18430888;47,76756492;Fichte
13,18464985;47,76756492;Fichte
13,18499082;47,76756492;Fichte
13,1853318;47,76756492;Fichte
13,18567277;47,76756492;Fichte
13,18601374;47,76756492;Fichte
```

**Figure 19**: Salzburg district of Hallein. Single trees with coordinates and tree species.



It is possible to say that most of the data gap(s) have been filled in this lab test, with the nota that the results presented here are covering the "*Exposure*" and "*Vulnerability*" parts of the proposed framework (see Section 4.3.1). However, the dataset used is from 2009, but after further research and deeper inspection of the resulting datasets (Table 17), it has been concluded that the dataset can still be relevant for today. For the Salzburger Land, spruce is the most dominant tree species with almost 3 million trees spread over all the districts of Salzburg (Figure 21). 80% of the total number of trees. These figures are from 2009, but they fit well with the figures from 2022 (Figure 21) and the trend of decreasing spruce numbers reported in the Austrian Forest Report 2023. Furthermore, spruce is still the most common tree species in Austria with a share of almost 50% on a national basis ("Austrian Forest Report 2023,"), (Jandl 2020).

**Table 18**: Trees species per region.

| District | Beech | Oak | Spruce | Larch | Fir | SUM |
|---|---|---|---|---|---|---|
| Salzburg Stadt (City) | 1919 | 3063 | 5008 | 3356 | 0 | **13346** |
| Tamsweg | 7 427 | 5 804 | 480 829 | 6049 | 361 | **500 470** |
| Zell Am See | 50662 | 34494 | 994342 | 64663 | 208 | **1144369** |
| Salzburg Umgebung | 71125 | 64891 | 221008 | 92504 | 41 | **449569** |
| Johann Im Pongau | 45118 | 42774 | 992894 | 52842 | 718 | **1134346** |
| Hallein | 49987 | 42527 | 252903 | 58015 | 67 | **403499** |
| SUM | **224 319** | **190 490** | **2 941 976** | **274073** | **1395** | **3 632 253** |
| Of total SUM (%) | **6** | **5** | **81** | **8** | **0** | N/A |
| Waldinventar for Land of Salzburg (%) (Tree species: Salzburg, 2022) | **8** | **0** | **73** | **5** | **3** | N/A |

The only missing dataset is that on damaged trees (as part of the "*Hazard*" block from Section 4.3.1), which would require an additional and more advanced approach. Applying steps 1-2 as described above, it proved even more difficult to obtain such information. Although news portals are quite active in reporting such events, they are scarce in more useful information, while data and information portals give general figures (e.g., total monetary damage due to a storm). However, it is possible to draw some conclusions by looking at Table 18 and the presence of tree species along the roads. Further, the dialogue with CoP members will be sought to assess potential damage data sources.

As mentioned above, spruce is the dominant tree species, which is also the case for the trees along the road network. This would mean that the characteristics of a spruce tree (e.g., shallow roots) would have to be included in any assessment of the impact of high winds on the road network. Finally, the above methodology can be easily applied to extract tree information for other types of infrastructure (e.g., power grids, gas pipelines, critical infrastructure), as well as for river and stream flows, e.g., to address flooding scenarios.

*Figure 20: Spruce is the dominant tree species in the Land of Salzburg, as well as in Austria as a whole (see Table 17). Here depicted is the Norway Spruce ("Spruce," 2024).*

ÖSTERREICHISCHE WALDINVENTUR

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Bundesforschungszentrum für Wald

**IHRE ABFRAGE**
Stammzahl / Baumarten / Ertragswald
REGION: Salzburg
PERIODE: 2016/21

| | STAMMZAHL | | % von GESAMT-STAMM-ZAHL |
|---|---|---|---|
| | 1000 Stämme | ± | |
| Fichte | 173 456 | 13 164 | 73,1 |
| Tanne | 7 677 | 1 560 | 3,2 |
| Lärche | 12 278 | 1 823 | 5,2 |
| Weißkiefer | 394 | 177 | 0,2 |
| Schwarzkiefer | 0 | — | 0,0 |
| Zirbe | 795 | — | 0,3 |
| Weymouthskiefer | 50 | — | 0,0 |
| Douglasie | 0 | — | 0,0 |
| sonstiges Nadelholz | 29 | — | 0,0 |
| SUMME NADELHOLZ | 194 678 | 14 056 | 82,0 |
| Rotbuche | 19 160 | 2 868 | 8,1 |
| Eiche | 231 | 103 | 0,1 |
| Hainbuche | 1 028 | — | 0,4 |
| Esche | 6 002 | 1 622 | 2,5 |
| Ahorn | 6 125 | 1 664 | 2,6 |
| Ulme | 400 | — | 0,2 |
| Edelkastanie | 0 | — | 0,0 |
| Robinie | 0 | — | 0,0 |
| Sorbus und Prunus | 1 611 | 632 | 0,7 |
| Summe Hartlaub | 34 557 | 4 630 | 14,6 |
| Birke | 1 403 | 526 | 0,6 |
| Schwarzerle | 1 234 | — | 0,5 |
| Weißerle | 2 463 | 899 | 1,0 |
| Linde | 113 | — | 0,0 |
| Aspe, Weiß-, Silberpappel | 367 | — | 0,2 |
| Schwarzpappel | 0 | — | 0,0 |
| Hybridpappel | 25 | — | 0,0 |
| Baumweide | 2 431 | — | 1,0 |
| sonstiges Laubholz | 0 | — | 0,0 |
| Summe Weichlaub | 8 036 | 2 076 | 3,4 |
| SUMME LAUBHOLZ | 42 592 | 5 084 | 18,0 |
| ERTRAGSWALD | 237 270 | 15 670 | 100,0 |

QUELLE: www.waldinventur.at STAND: 13 Juni 2022

**Figure 21**: Forest cadaster for the province of Salzburg showing the tree species, number of trees (in 1000s), and distribution in percentage.

## 4.4 Test D: Vulnerability and economic impact assessment on critical assets damaged by wildfire – South Aegean Region (SAR)

### 4.4.1 Summary and objectives of Test D

The aim of lab test D is the vulnerability and impact assessment of critical infrastructure due to forest fires. The lab test will be performed in Rhodes Island, which is historically impacted by extreme forest fires. This lab test aims to quantify the infrastructure vulnerability of the island, using the actual 2023 forest fire that damaged approximately 20% of the island, as a hazard dataset. This analysis focused on:

- Road network
- Electrical grid
- Natural areas
- Buildings (private house)

**Table 19**: Test D summary.

| Test D summary | | | |
|---|---|---|---|
| **Methodology** | Vulnerability and Impact Assessment | **Data-gap** | Analytical data for damages and costs of infrastructure |
| **Hazard** | Forest fires | **CSF of the test** | SAR |

### 4.4.2 Activities of Test D

The data needed for the vulnerability analysis, based on the analysis framework presented in D3.6 (ICARIA, 2024c), are mainly geospatial data for characterizing the critical infrastructure, under investigation, and the damaged area by the 2023 forest fire. This approach identifies the infrastructure components that are located in the damaged area. By linking these data with the economic data related to the cost of reparation for each type of infrastructure, will allow the vulnerability and economic impact assessment of the critical infrastructure under investigation. The economic data, needed for such analysis, are limited due to bureaucratic reasons since the reparation costs are still calculated and/or are not public domain. The existing data available for such analysis are mainly from the SAR regional authority and the Hellenic Electricity Distribution Network Operator S.A. (HEDMO). To overcome this barrier and to quantify the economic impact of the remaining critical infrastructure, until the official data are available, the taxable fair market value for the buildings and the average cost per kilometer of road restoration have been used, based on reparation contracts of SAR with various constructors.

The data required (Table 19 and Table 20) for Lab Test D implementation are based on the need for a vulnerability framework of ICARIA, D3.6. Table 17 shows the existing data used for the vulnerability analysis, while Table 18 shows the data gaps for this analysis and the alternative/temporal data, used for the economic impact assessment.

**Table 20**: Available geospatial data groups information.

| Data Group | Parameters | Source of Information | Statistical analyses made |
|---|---|---|---|
| Burned area from the 2023 forest fire | Vector data (Shapefile) enclosing the burned areas of Rhodes Island during the forest fire of 2023 | Ministry of Environment - National Forest Service | Georeferencing |
| Burned areas from past forest fires | Vector data (Shapefile) enclosing the burned areas of Rhodes Island in the past (Incomplete) | | |
| Critical infrastructure | Road network | Open street maps | Geospatial analysis |
| | Buildings | | |
| | Electrical power grid | Open street maps / HEDMO | |
| | Green areas/Protected Natural Areas | Ministry of Environment - National Forest Service/CORINE | |
| | Water distribution network (unavailable) | DEYA Rhodes | N/A |



**Table 21**: Economic data groups and alternative solutions.

| Data Group | Parameters | Source of Information | Statistical analyses made |
|---|---|---|---|
| Economic data | Electrical network reparation costs (Obtained) | HEDMO | Cost estimation per electrical network component |
| | Road network (Missing) | Hellenic Government | Cost per km of road network |
| | Temporary solution | | Average cost per km based on contracts |
| | Buildings (Missing) | Hellenic Government | Cost per building |
| | Temporary solution | | Taxable fair market value |

The vulnerability assessment framework is in detail presented in ICARIA D3.6(ICARIA, 2024c). The concept behind this framework is to identify each type of infrastructure that is located in the damaged area from the 2023 forest fire, which affected Rhodes Island. This approach captures the geographic distribution of the elements of each critical infrastructure group, giving a clear indication of the assets that are vulnerable to forest fires in the region. This approach can be further improved when additional information regarding past forest fire events can be collected. Once the elements of each asset are identified, the vulnerability of each asset can be estimated. At the next step and with the addition of the missing data presented in Table 21, the economic vulnerability of each sector can be also estimated.

To address the existing data gaps, noted in section 4.4.1, the following steps will be followed:

a) **Continuous search for up-to-date reparation costs**: The use of the actual reparation cost data is important for the accurate quantification of the economic vulnerability.
   i. To address this issue, the CSF will update the assessment results once the actual reparation data are publicly available by the government.
   ii. Deep dive into insurance data, if they can be provided, from the insurance companies.
b) **Use alternative/temporary economic data**: To overcome this data barrier, alternative economic data will be used, based on the data available by the CS. SAR provided financial data related to contacts for a variety of repair works on the critical assets (mainly road network). In the case of buildings, the taxable fair market value for these parts of Rhodes Island will be used

### 4.4.3 Results of Test D

The geospatial analysis results of the vulnerability assessment framework are presented in Figure 22, below. Each asset is presented in two colors (green and red) that are characteristic of their vulnerability, due to forest fires. The vulnerability of each sector is presented in Table 21.

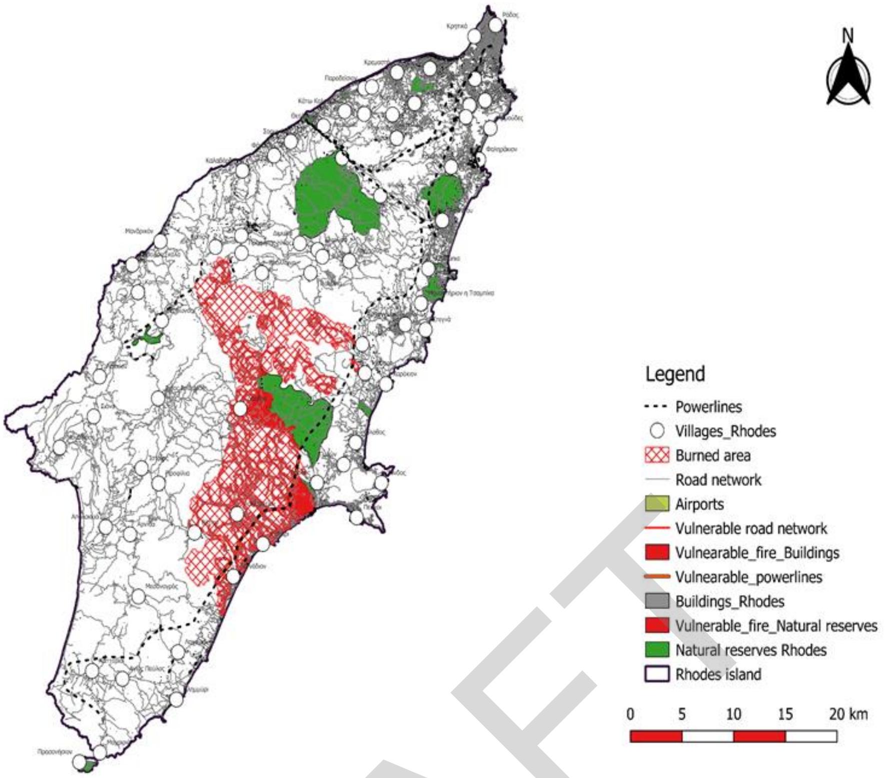


**Figure 22**: Geospatial distribution of total and vulnerable critical infrastructure on the island of Rhodes.

**Table 22**: Vulnerability analysis' results with the existing data.

| Asset | Asset extend | Vulnerable extend | Vulnerability (%) |
|---|---|---|---|
| Buildings (number) | 68637 | 2008 | 3 |
| Road network (km) | 4818 | 446 | 9 |
| Power distribution network (km) | 163 | 15.6 | 10 |
| Green areas (km$^2$) | 99.95 | 13.27 | 13 |

# 5 Conclusions

The scarcity of data remains an open issue despite the EU's efforts for data accessibility, reproduction, and transferability in the framework of climate multi risk assessment. Thus, modeling climate change and resilience remains prone to gaps and uncertainties demanding reasonably accurate treatments. Within the purposes of the ICARIA project, a wide range of data gap groups have been identified, requiring tools and frameworks to surpass such issues. A crucial step in this process remains the lab testing where selected data gaps are treated by novel procedures and methodologies proposed within the ICARIA project and by additionally, utilizing and extending results and tools from other EU-related projects. In WP1, where climate projections and modeling inputs are addressed, the necessity for a lab test task is profound. Thus, in the case study areas —Barcelona, Salzburg, and South Aegean— methodologies from previous WP1 tasks are applied to treat data gaps related to land cover dynamics, pluvial floods, windstorms, and forest fires. Specifically, these tests cover gaps in temporal series, GDP, population density, urban drainage infrastructure, electricity asset's location, damaged road network, damage to buildings, broken or fallen trees, reparation costs, and more, creating a recommendation-like template that can be extended in the subsequent steps within the ICARIA project. Additionally, preliminary results, along with synthetic tables compiling necessary data gap characteristics, are presented. When a surplus of data will be gathered during trials and mini-trials including the interlinks between more extended sets of variables and treating more complex scenarios (e.g., cascading events) the lab tests will reliably address data gaps, refining optimal methodologies for data collection and transformation, and producing informative maps and synthetic tables. Finally, within the purposes of WP1, the following steps will continue to explore the integration of data-driven methodologies and current tools, sourced from D1.3, to evaluate their effectiveness in addressing climate change-related data gaps.

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# Annex A: Lab test data gap tables

This section of the deliverable includes a collective source of information on data gaps for each lab test, allowing for easy access and findability of the key components of each test regarding data gaps. The characteristics can be summarized as follows:

- Receptor: Description of the data on the specific domain/infrastructure, etc.
- Hazard: Description of the related hazard.
- Data Gap Group: Grouping of the high-level, joint, name of the data gaps related to the asset.
- Exact Data Gap: Description of the exact data gap that needs to be filled/addressed (Several of them may be covered by the same approach/dataset/source).
- Priority: Describes the priority level of the "exact data gap", and is categorized into three (3) levels: (i) High, (ii) Medium, and (iii) Low.
- Description: "Data Gap Group" detailed description.
- Resolutions: Reparteed in two categories: (1) minimal spatial, and (2) minimal temporal.
- Date and time: Determination of when the data gap has occurred or is identified.
- Area of Interest/Location (GIS-compatible file (polygon, points, line) - KML, TIFF, etc.): Description of a file that defines the area for which the gap is relevant. This can be produced in, e.g., QGIS, and exported. The types can include but are not limited to polygons, points, and lines.

## A.1 Data Gaps: Lab test A

As recalled in ICARIA *D1.2* (ICARIA, (2020b)), results obtained using the methodology proposed should be analyzed taking into consideration the natural data gaps produced within the methodology framework as well as the data gaps given by the datasets used during the execution of said method.

**Table A1**: Data Gaps table: Lab test A.

| Receptor | Hazard | Data Gap Group | Exact Data Dap | Priority | Description | Resolution (minimal spatial) | Resolution (maximal spatial) | Date (and time) | Area of Interest/Location |
|---|---|---|---|---|---|---|---|---|---|
| N/A | N/A | Data on land use | Spatial areas information missing | High | Missing data on specific polygons of interest | Province | 6 years | All possible events | QGIS vectorial polygons |
| N/A | N/A | Data on temporal land use | Temporal series | Medium | Missing data on specific years for the land use of a specific polygons of interest | EU | 6 years | 2000-2006, 2006-2012, 2012-2018, 2024 (Not available yet) | Temporal series of missing years QGIS polygons |
| N/A | N/A | Data on drivers/predictors | GDP | Low | Missing data is not yet provided or estimated | City Council | 1 year | Year: 2024 | Data attached to a GIS polygon |

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| | | | | | about a specific year's GDP | | | | |
| N/A | N/A | Data on drivers/predictors | Population density | Low | Missing data is not yet provided or estimated about a specific year's population density | City Council | 1 year | Year: 2024 | Data attached to a GIS polygon |
| N/A | N/A | Data on drivers/predictors | Deforestation | Low | Missing data is not yet provided or estimated about a specific year's deforestation rate | City Council | 1 year | Year: 2024 | Data attached to a GIS polygon |
| N/A | N/A | Data on drivers/predictors | Abandonment of land | Low | Missing data is not yet provided or estimated about a specific year's abandonment land | City Council | 1 year | Year: 2024 | Data attached to a GIS polygon |

## A.2 Data Gaps: Lab test B

**Table A2**: Data Gaps table: Lab test B.

| Receptor | Hazard | Data Gap Group | Exact Data Dap | Priority | Description | Resolution (minimal spatial) | Resolution (maximal spatial) | Date (and time) | Area of Interest/Location |
|---|---|---|---|---|---|---|---|---|---|
| N/A | Pluvial flooding | Flooding model data | Urban drainage infrastructure | High | Structural information (e.g., diameters, geometry, depth, length, slope) of physical elements of a drainage network (e.g., manholes, pipes, outfalls) | Singular structure level | N/A | N/A | Model domain |
| N/A | Coastal flooding | Hazard assessment | Sea level, wave height, and tide measurements | High | Spatial and temporal accurate measurements of sea behavior during storm surge events | Order of $km^2$ | Minutely resolution | Events of interest for model calibration and validation | Model domain |
| N/A | Pluvial flooding | Hazard assessment | Event information | High | This gap involves two (2) data sub-groups: (a) Measurements of water level in the sewer | Singular structure level | Minutely resolution | Events of interest for model calibration and validation | Model domain |

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| | | | | | network pipes or outfalls, and (b) Operational data of anti-flooding devices such as tanks, pumps, or valves. | | | | |
| N/A | Any | Exposure data | Electricity asset's location | High | Information about the location of electricity location assets and data about existing measures of resilience against hazards of interest | Singular structure level | N/A | N/A | Model domain |
| N/A | Any | Vulnerability assessment | Vulnerability curves | High | Information to develop vulnerability curves to express impact (economic or operational) on assets with respect to hazard levels (e.g., € of damage vs water level or % of chance of equipment | N/A | N/A | N/A | N/A |

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| | | | | | failure vs air temperature) | | | | |
| Any | Any | Hazard assessment | Heatwave and heat island effect modeling | High | Time series of temperature with hourly resolution in the model domain to accurately model the impact of heatwaves on risk receptors. | Order of $km^2$ | Hourly resolution | Events of interest for model calibration and validation | Model domain |

## A.3 Data Gaps: Lab test C

**Table A3**: Data Gaps table: Lab test C.

| Receptor | Hazard | Data Gap Group | Exact Data Dap | Priority | Description | Resolution (minimal spatial) | Resolution (maximal spatial) | Date (and time) | Area of Interest/Location |
|---|---|---|---|---|---|---|---|---|---|
| Property | Flooding | Data on damaged areas (cellars, floors and related costs) per identified event | Number<br>Location (coordinates)<br>Costs | Medium<br>High<br>High | Housing damage (cellar) data after the flooding event affecting the Salzburg area for different events | If possible, per house (won't be feasible); smallest possible spatial resolution, probably postal code | Event-based | N/A | Salzburg rural areas => if not available could be taken from other Austrian (maybe German) regions => would need to discuss differences in building types and related uncertainties |
| Transport | Flooding | Damaged roads | Location<br>Damage severity (e.g., low, moderate, critical)<br>Costs | High<br>Medium<br>Medium | Road damage data right after the flooding event affecting the Salzburg rural area | 10 meters<br>Area of road damaged and related costs | Before and after flood<br>Costs after flooding | N/A | Salzburg rural areas => if not available could be taken from other Austrian (maybe German) regions => would need to discuss differences in building types and related uncertainties |

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| Electricity | Flooding | Impacted infrastructure | Location<br>Costs of damage | Medium<br>Medium | Monetary Damage to infrastructure, indirect damage due to reduced energy supply | Per hydro power plant and event | N/A | N/A | Salzburg rural areas => if not available could be taken from other Austrian (maybe German) regions => would need to discuss differences in building types and related uncertainties |
| Electricity | Wind speed / storm | Broken and/or fallen trees | Number<br>Tree type<br>Location<br>Severity (i.e., see above) | High<br>High<br>High<br>High | Trees that were damaged during the storm, if they are situated close to electricity network or power plant and thus caused failure or reduced supply (either due impacting network, or power plant) | 10m | Before and after storm event | 26.01.2019<br>All possible events | Salzburg rural areas => if not available could be taken from other Austrian (maybe German) regions => would need to discuss differences in building types and related uncertainties |
| Transport | Winds speed /storm | Broken and/or fallen electricity polls | Number<br>Severity<br>Location | Medium<br>Medium<br>Medium | Number of electricity poles that were damaged during the storm XY. Necessary to | Costs to "*free*" the street from trees | Per event | All possible events | Salzburg rural areas => if not available could be taken from other Austrian (maybe German) regions |

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| | | | | | assess the damage impact of the storm. | | | | => would need to discuss differences in building types and related uncertainties |
| Housing | Winds speed /storm | Destroyed Roofs | Location | High | Storm dismantles roofs => monetary damage | Post code | Per event | All possible events | Salzburg rural areas => if not available could be taken from other Austrian (maybe German) regions => would need to discuss differences in building types and related uncertainties |

## A.4 Data Gaps: Lab test D

**Table A4**: Data Gaps table: Lab test D.

| Receptor | Hazard | Data Gap Group | Exact Data Dap | Priority | Description | Resolution (minimal spatial) | Resolution (maximal spatial) | Date (and time) | Area of Interest/Location |
|---|---|---|---|---|---|---|---|---|---|
| Buildings | Forest fires | Economic | Currently not available | Medium | Reparation costs per property damaged | Building | Event-based | August 2023 | Rhodes island, Greece: Vector data (Shapefile) or individual financial reports |
| Road network | Forest fires | Economic | Currently not available | Medium | Reparation costs per km of road network damaged | km | Event-based | August 2023 | Rhodes island, Greece: Analytical financial report |
| Power grid | Forest fires | Economic | Currently not available | Medium | Reparation costs per km of power grid damaged | km | Event-based | August 2023 | Rhodes island, Greece: Analytical financial report |
| Water distribution network | All | Geospatial | Not available | Low | Vector data of the water distribution network | m | N/A | N/A | Rhodes island, Greece: Vector data (Shapefile) |

## Annex B: Data Management Statement

**Table B.1.** Data used in preparation of ICARIA Deliverable 1.4

| Dataset name | Format | Size | Owner and re-use conditions | Potential utility within and outside ICARIA | Unique ID |
|---|---|---|---|---|---|
| **N/A** | N/A | N/A | N/A | N/A | N/A |

**Table B.2.** Data produced in preparation of ICARIA Deliverable 1.4

| Dataset name | Format | Size | Owner and re-use conditions | Potential utility within and outside ICARIA | Unique ID |
|---|---|---|---|---|---|
| **N/A** | N/A | N/A | N/A | N/A | N/A |

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More info: **www.icaria-project.eu**