Ref. Ares(2023)2360447 - 31/03/2023

CLIMATE-RESILIENT REGIONS THROUGH SYSTEMIC SOLUTIONS AND INNOVATIONS

Socio-environmental systems participatory models and analysis techniques – Initial version

Deliverable 3.2

WP3: Dynamic Multi-Sectoral Resilience Modelling and Assessment Framework

Authors: Anastasios Zafeiropoulos, Christina-Maria Androna, Eleni Fotopoulou, Ioanna Mandilara, Symeon Papavassiliou (ICCS), Dimitris Kofinas, Nefta-Eleftheria Votsi, Eleni Athanasopoulou, Iphigenia Keramitsoglou, Panagiotis Sismanidis, Chris Kiranoudis, Christos Giannakopoulos, Konstantinos V. Varotsos, George Katavoutas, Evangelos Gerasopoulos, Theodoros Karakasidis (UTH), Chrysi Laspidou (UTH)

Date: 31/03/2023

This project has received funding from the European Union's Horizon 2020 innovation action programme under grant agreement 101037424.

Deliverable Number and Name	D3.2 - Socio-environmental systems participatory models and analysis techniques – Initial version
Work Package	WP3 – Dynamic Multi-Sectoral Resilience Modelling and Assessment Framework
Dissemination Level	Public
Author(s)	Anastasios Zafeiropoulos, Christina-Maria Androna, Eleni Fotopoulou, Ioanna Mandilara, Symeon Papavassiliou (ICCS), Dimitris Kofinas, Nefta-Eleftheria Votsi, Eleni Athanasopoulou, Iphigenia Keramitsoglou, Panagiotis Sismanidis, Chris Kiranoudis, Christos Giannakopoulos, Konstantinos V. Varotsos, George Katavoutas, Evangelos Gerasopoulos, Theodoros Karakasidis (UTH), Chrysi Laspidou (UTH)
Primary Contact and Email	Anastasios Zafeiropoulos (tzafeir@cn.ntua.gr)
Date Due	31/03/2023
Date Submitted	31/03/2023
File Name	ARSINOE_D3.2
Status	Final
Reviewed by	Gerardo Anzaldua (BRC)
Suggested citation	Anastasios Zafeiropoulos et al. (2023) Socio-environmental systems participatory models and analysis techniques – Initial version. ARSINOE Deliverable 3.2, H2020 grant no. 101037424

© ARSINOE Consortium, 2023

This deliverable contains original unpublished work except when indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation, or both. Reproduction is authorised if the source is acknowledged.

This document has been prepared in the framework of the European project ARSINOE. This project has received funding from the European Union's Horizon 2020 innovation action programme under grant agreement no. 101037424.

The sole responsibility for the content of this publication lies with the authors. It does not necessarily represent the opinion of the European Union. Neither the EASME nor the European Commission are responsible for any use that may be made of the information contained therein.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Socio-environmental systems participatory models and analysis techniques are a set of methodologies that allow stakeholders and inter-disciplinary scientists to actively collaborate and participate in decision-making processes regarding socio-environmental issues. These models are designed to facilitate collaboration among different groups and to promote the integration of scientific knowledge and local knowledge (e.g., knowledge coming from community science). By incorporating diverse perspectives, these models can lead to more effective and sustainable solutions.

The participatory models and analysis techniques involve a range of tools and approaches that can be adapted to different contexts and scales. These tools can include stakeholder mapping, participatory mapping, scenario planning, and multi-criteria analysis, among others. These techniques aim to create a safe and inclusive space for dialogue and deliberation, where participants can express their views and concerns, identify common goals and interests, and co-create solutions. Overall, the Socio-environmental systems participatory models and analysis techniques can provide a valuable framework for addressing complex socio-environmental issues. By involving stakeholders in the decision-making process, these models can help to build trust, enhance social capital, and foster a sense of ownership and responsibility among participants. Furthermore, these models can contribute to more equitable and sustainable outcomes, by ensuring that the voices of marginalized and vulnerable groups are heard and taken into account.

In this document, the participatory socio-environmental systems modeling techniques that are developed in the ARSINOE project are detailed. Focus is given on the exploitation of the knowledge management infrastructure that is developed in the project to tackle challenges related to participatory socio-environmental systems modeling. A systems innovation approach is adopted to guide the participatory socio-environmental systems modeling process by identifying the underlying structures and processes that contribute to the problem being addressed, and developing solutions that address those underlying causes rather than just treating the symptoms. It should be noted that the current version provides the outcomes achieved up to now in the project, while a revised version of the document is going to be made available by the M30 of the project (March 2024).

1.0 Introduction

A strong interplay exists between human and naturas societies, where human societies are exerting a significant influence on natural environments, and conversely, natural phenomena are affecting our communities in an unprecedented manner. To comprehend the underlying factors that will enable us to exercise greater control over this interplay in the future and ensure a more virtuous cycle between human societies and natural environments, it is imperative to jointly model and analyze the fundamental and inescapable interaction between natural and societal systems (Zafeiropoulos et al., 2021). This is particularly relevant in the context of climate change, as it is a complex and multifaceted problem that necessitates a comprehensive and transdisciplinary approach to develop effective solutions to mitigate and adapt to its impact. One possible way to co-create solutions and promote resilience to climate change impacts is through collaboration among scientists from diverse disciplines and the involvement of stakeholders from various sectors and communities.

Towards this direction, socio-environmental systems (SES) modeling integrates knowledge and perspectives across a range of systems, into conceptual and computational tools that explicitly recognize how human decisions affect the environment (Elsawah et al., 2020) and the uncertain nature of the individual systems and their interrelationships. The development of participatory SES models arises as a promising approach to address SES-related problems. In the ARSINOE project, we consider the SES participatory modeling as a process that is related to the adopted Systems Innovation Approach (SIA), while a strong link exists between the SES analysis processes that can be supported through the Data Hub and the SustainGraph (the Knowledge Graph (KG) developed in the project and detailed in D4.6) (Fotopoulou et al., 2022). Specifically, the data collected in the Data Hub and semantically represented in the SustainGraph are fed as input to the analysis processes that are required by the participatory SES models. Vice versa, the output of the analysis processes can populate the Data Hub and the SustainGraph with further data.

In this deliverable, focus is given on detailing the main challenges that have to be faced to effectively support participatory SES modeling and the design of the relevant framework that will be adopted within ARSINOE. A set of methods that can be applied for supporting analysis processes of the developed models is listed. Based on this framework, a set of participatory SES models are going to be developed and evaluated. Draft versions of the participatory SES models that are under development in the project are provided, while these models will be fully documented in the revised version of D3.2 in D3.3 that is due on M30 of the project.

The structure of the deliverable is as follows. In Section 2, the main challenges faced for the development of participatory SES models are presented following a literature review on the field. The part of the challenges that are targeted to be tackled within ARSINOE are identified. In Section 3, the Systems Innovation Approach that is adopted within ARSINOE is shortly described, focusing on the way that it facilitates participatory modeling processes. In Section 4, initial versions of part of the participatory SES models that are under development in the project are presented. Short description of the current version of the models, their main objectives and the participatory approach that is followed is provided. In Section 5, focus is given on the exploitation of the knowledge management infrastructure developed within the project in a twofold scope: taking advantage of the available data as input for the SES models; or populating the ARSINOE knowledge infrastructure with the outputs of the modeling processes. Section 6 concludes the deliverable, while it also provides information regarding the work plan towards the release of D3.3 in M30 (March 2024).

2.0 Challenges and methods for the development of socio-environmental systems participatory models

2.1 Definitions

Participatory modeling for socio-environmental systems involves a collaborative and iterative approach to modeling that engages stakeholders, including community members, policymakers, and researchers, in the modeling process. This approach acknowledges that socio-environmental systems are complex and multifaceted, and recognizes the importance of integrating diverse perspectives, knowledge, and values in modeling efforts. Participatory modeling can help to build trust, facilitate communication, and foster learning among stakeholders, and can lead to more robust and effective decision-making processes that are better aligned with the needs and aspirations of the communities involved. Participatory modeling can help to ensure that modeling efforts are relevant and responsive to the needs and aspirations of the communities involved, ultimately leading to more sustainable and equitable outcomes.

Participatory modeling has become prevalent in various fields such as health, development planning, and environmental research. The main objective is to promote stakeholder interactions and facilitate the development of shared, mutually understood models of complex systems that can be used to inform effective problem-solving and policy decisions. This approach aims to bring stakeholders together to reach a consensus on a common modeling framework, which can enhance the overall decision-making process (Quimby et al., 2023). Various definitions are provided for participatory modeling in the literature. In Stave (2010), participatory modeling is defined as "...an approach for including a broad group of stakeholders in the process of formal decision analysis" (Stave (2010)) while in (Voinov et al. (2018)), PM is defined as "... a purposeful learning process for action that engages the implicit and explicit knowledge of stakeholders to create formalized and shared representations of reality." Within the ARSINOE project, we consider participatory modeling as a process where various actors are engaged to conceptualize, formally model and analyze complex socio-environmental systems that are identified in the various case studies. The actors include -among others- socio-environmental scientists, data scientists and stakeholders that are participating in the living labs organized by the project.

2.2 Challenges

Recently, a lot of work has been done on the specification of the main challenges that have to be tackled for the development of SES participatory models. Following, we provide an overview of the available work on the field. In (Elsawah et al., 2020), the authors detail eight grand challenges that need to be overcome to accelerate the development and adoption of SES modeling. These challenges regard:

- The need to **bridge epistemologies across disciplines** considering the epistemological pluralism in the concepts used and the potential misunderstandings and conflicts that may appear. Semantic alignment of terms is required to enable scientists coming from different disciplines to collaborate. Semantic alignment has to be combined with mechanisms to evaluate the validity and quality of the data. Furthermore, the different methodologies and collaboration norms that may be applied per discipline have to be considered and -where possible- bridged, taking into account the engagement of heterogeneous actors from different backgrounds. Sharing and usage of data in public repositories is required to improve their availability, as well as the potential for reproducibility of experiments.
- The need to **manage the sources of uncertainty in** the data, model structure and model parameters. Different sources of uncertainty may be introduced that in some cases may be also

interlinked. Deep uncertainty is introduced in cases where there is disagreement among the people involved in the modeling process.

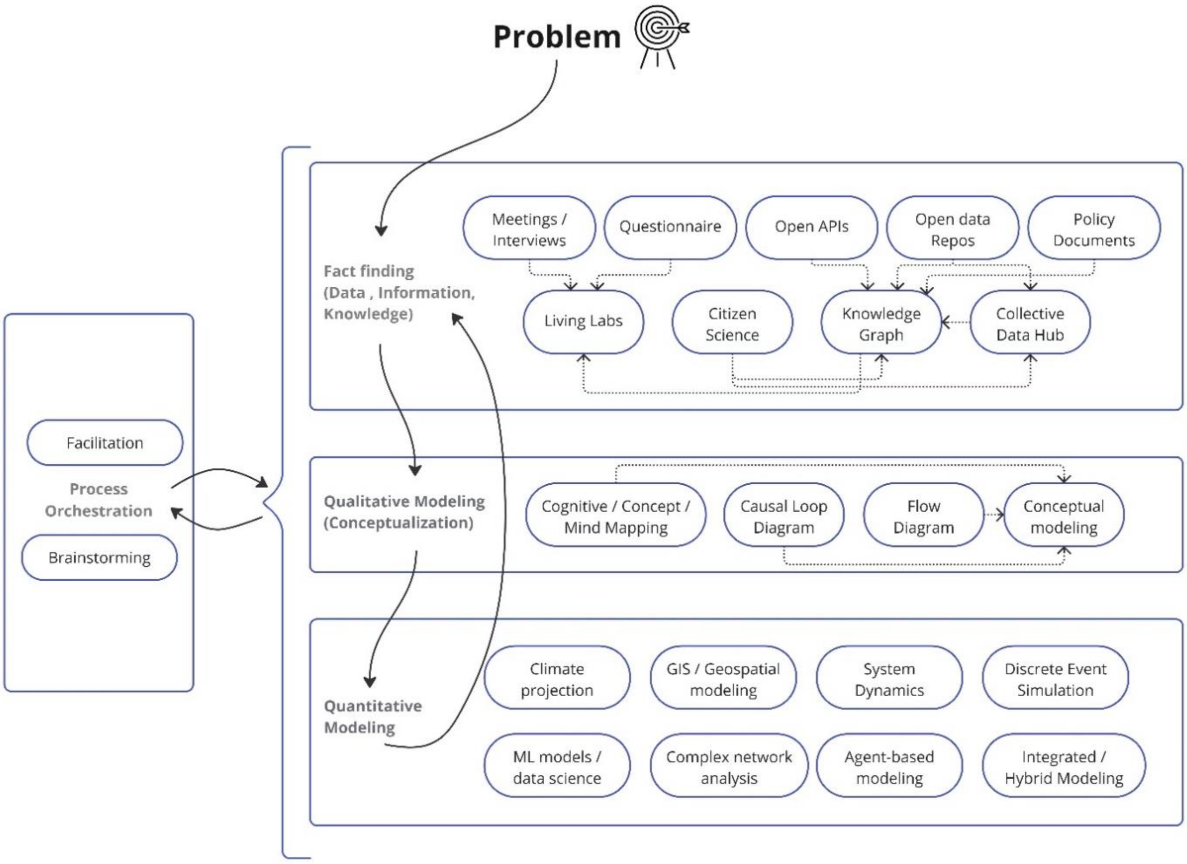
- The need to **combine qualitative and quantitative methods and data** sources, considering quantitative data (e.g., time series data) coming from various data repositories as well as qualitative data (e.g., text, processes description, assessment data). Depending on the research question and the available data, the mix of the quantitative and qualitative information that is fed for analysis has to be decided. Mixed methods are applied for the analysis part.
- The need to cope with **different data scales** from a spatial, temporal and organizational scope. SES modeling may consider different ways of partitioning of the examined geographical areas, while the temporal coverage and resolution may also vary. A coherent matching of the available data in such scales is required to enable their analysis. Human behavior may be examined from an individual or group/community perspective, introducing further complexity in the modeling process.
- The need to develop methods to **capture systemic changes in SES**. SES are dynamic, while gradual changes in their past behavior may affect their future status. It is important to be able to capture dynamic changes and transitions of SES as an integral characteristic of the modeling process. The existing modeling techniques are static in the definition of the system dynamics (e.g., rules or equations that guide the dynamics).
- The need to **integrate the human dimension** in the modeling of SES systems by considering agent-based approaches to represent human behavior by heterogeneous actors (e.g., farmers, households, firms, etc.). Various interdisciplinary research teams investigate coupled natural-human systems, however in a limited scope (Shin et al., 2022). There is a need to better align the theory and the data for guiding social decision rules, as well as to consider behavioral aspects as integral part of the models.
- The need to **elevate the adoption of SES models and impacts on policy design and implementation**. The outcome of the models has to be used to support collaborative decision making. Participatory modeling can combine the innovative capacity of various stakeholders, formalize collective representations of complex problems and promote a sense of ownership by the involved parties. In this way, decision makers may be more likely to adopt the outcomes provided by the models.
- The need to **leverage new data types and sources**, considering data coming from social media, search engines, mobile applications and devices, wearable devices and social networks. Synthesis of heterogeneous data coming from diverse data sources has to be supported.

Following, in Section 4.1.2, we provide details regarding the way that we can tackle part of the aforementioned challenges based on the knowledge infrastructure made available by the project.

2.3 Methods

The tools and methods used during participatory modeling projects are expected to promote system understanding and awareness for all stakeholders (Voinov et al., 2018). There are numerous methods used in participatory modeling projects. In Figure 2.1, a typology of methods is presented as it is made available in (Voinov et al., 2018). In most cases, a combination of methods is taking place in the form of a workflow.

Figure 2.1 Participatory modeling methods.



The fact-finding stage of the participatory modeling process regards the collection of data, information and knowledge regarding the system to be modeled. This can be done in various ways based on access to specific data silos, including information coming from interviews, surveys, access to open data repositories and usage of open Application Programming Interfaces (APIs). The fact-finding stage may be revisited multiple times during a participatory modeling process.

The qualitative modeling stage of the participatory modeling process regards the design of conceptual and visual representations of the problem to be tackled, in the form of concepts and relationships among them. The relationships may have spatial and temporal dimensions. Qualitative modeling methods include -among others- the design of mind maps, flow diagrams, causal loop diagrams.

Following, the quantitative modeling stage is taking place (Voinov et al. (2018)). In the quantitative stage, we consider analysis that is based on the values provided to qualitative or conceptual metrics (e.g., scenario building, social network analysis), as well as analysis that is based on values that can be collected per metric with a temporal and/or spatial scale. In this stage, participatory SES modeling can employ various modeling techniques, such as agent-based modeling, system dynamics modeling, and the creation of reinforcement learning environments that simulate SES. These models can investigate environmental, economic, behavioral, and policy-making aspects individually or in combination. Regarding the modeling techniques, agent-based modeling is particularly useful in SES modeling as it simulates the actions and interactions of autonomous agents, allowing for explicit representation of decision-making by human actors (Gotts et al.,2019). It is a valuable tool for exploring the impact of human interactions on social and ecological patterns (Will et al.,2020).

In contrast, system dynamics is a methodology and mathematical modeling technique that provides an overview of complex issues and problems by representing the system as stocks and flows. While agent-based models represent disaggregated parts of a system, system dynamics models represent the aggregated system (Martin et al.,2015). The application of Machine Learning (ML) techniques can also aid in participatory SES modeling. One example is the combination of reinforcement learning (RL) and agent-based modeling (ABM) to better capture the probabilistic nature of the ecological footprint and its impact on environmental sustainability. While ABM relies on pre-defined rules by domain experts, integrating RL agents into the modeling process can better represent real-life scenarios where environmental variables evolve over time and are not always fully understood. Inverse reinforcement learning (IRL) can complement ABM by extracting behavioral rules from data and dynamically shaping them during the learning process (Lee et al.,2017). This approach frames learning behavioral rules as a problem of recovering motivations from observed behavior and generating consistent rules based on these motivations. This can be particularly useful in discovering rules that are difficult to define a priori and require deep insight into an agent's behaviors.

Process orchestration is considered across all the stages of a PM process and includes a set of methods (e.g., brainstorming, facilitation, role playing games) that enable the optimal execution of the various stages and the extraction of outcomes based on collective decisions and actions.

Furthermore, novel techniques are emerging that focus on the identification of patterns in the available data to assist the modeling and analysis processes. When faced with the assumption that every socio-environmental problem is entirely unique, it can be challenging to determine where to start. However, archetype analysis can assist in identifying patterns in the data. Archetypes refer to categories or groups with similar characteristics and patterns, even though individual cases may exhibit distinct traits. Archetype analysis can not only highlight common patterns that frequently arise in SES but also provide strategies for achieving sustainability across different contexts. In the context of SES, archetypes are fundamental and recurring patterns of feedback loops that generate comparable dynamics. Despite variations in individual cases, these archetypes enable researchers to identify comparable attributes and patterns (Palmer, 2022).

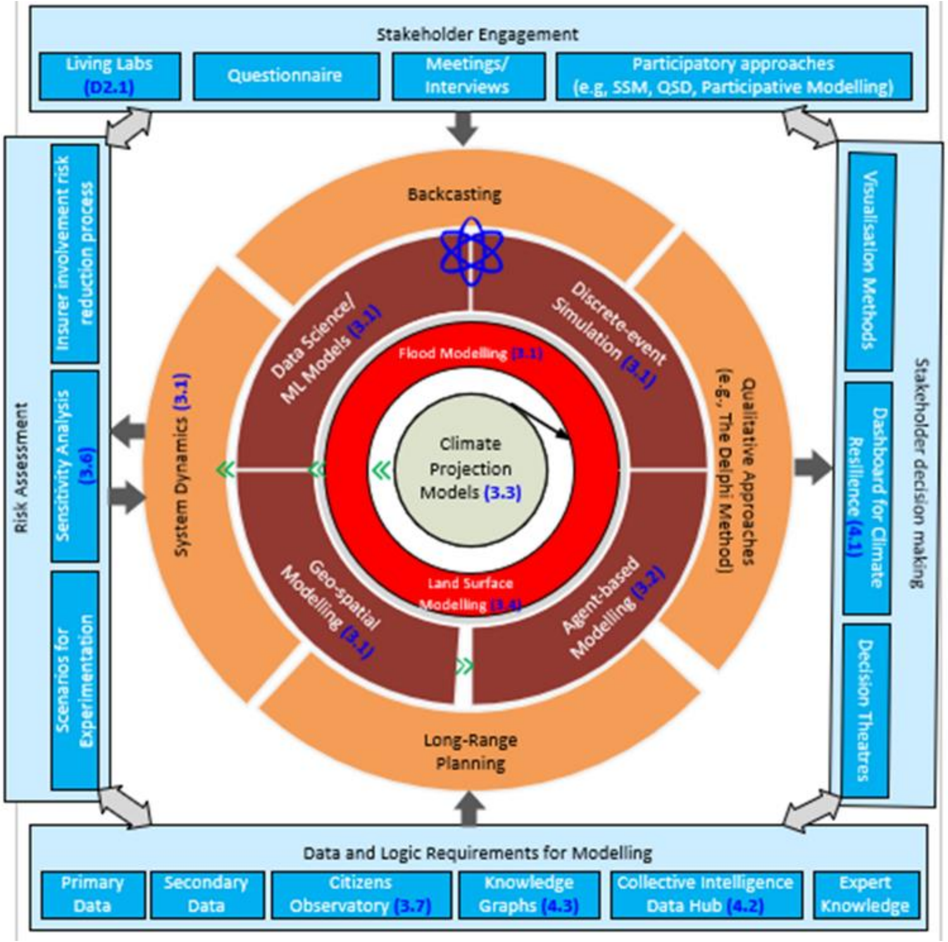
3.0 Participatory modeling based on a Systems Innovation Approach

A systems innovation approach is a holistic method that seeks to identify and implement changes in the underlying structures and processes of a complex system. It recognizes that complex systems are interconnected and dynamic, and that changing one element of the system can have ripple effects throughout the entire system. This approach is particularly useful for addressing complex socio-environmental challenges, such as climate change or resource depletion, that require systemic changes rather than incremental improvements. The systems innovation approach involves engaging stakeholders and using a participatory process to co-create and co-design solutions that address the underlying causes of the problem.

The systems innovation approach can be used to guide the participatory socio-environmental systems modeling process by identifying the underlying structures and processes that contribute to the problem being addressed, and developing solutions that address those underlying causes rather than just treating the symptoms. In practice, the systems innovation approach can be used to facilitate a participatory process in which stakeholders from different sectors and perspectives come together to co-create solutions to a complex socio-environmental challenge. The process involves identifying the key drivers and feedback loops that contribute to the problem, developing scenarios and models to test different intervention strategies, and engaging stakeholders in a continuous process of feedback and iteration to refine the solutions. By involving stakeholders in the process and addressing the underlying structures and processes of the system, the systems innovation approach can lead to more sustainable and equitable solutions to complex socio-environmental challenges.

Regarding the work in the ARSINOE project, we follow a bottom-up approach in many of its activities to optimize the acceptance and uptake of its solutions and develop well-informed analyses of the interactions between bio-physical and socio-economic systems, but also the implications that one system brings another. The stakeholders including citizens participate in different threads of the project, such as i) the collection of data, through citizen science, ii) the selection of interventions and providers, through the Climate Innovation Window and the open tenders, iii) the assessment of willingness to pay, through the choice experiments and virtual reality experience, iv) the capacity building thread, through the train-the-trainers exercise, and v) the participatory modeling, through the interactions between the Arsinoe modelers and stakeholders, in the Living Lab workshops. The participatory approach in the system modeling is also represented in the resilience wheel (Figure 3.1), the Arsinoe's resilience framework, that enables interactions between the Stakeholder Engagement pillar and the Risk Assessment pillar. This interaction implies that the Stakeholders co-shape the system analysis implemented by Arsinoe team in different levels. The Stakeholders reveal what are the geographical, bio-physical, and socio-economic boundaries of the case study, they indicate hidden synergies and trade-offs that might be not well documented or investigated, or that might be case specific, and, finally, they draw a path towards a vision, through the back-casting exercise choosing the interventions they need to be simulated and tested.

Figure 3.1 Arsinoe's Resilience wheel for participatory modeling.



In the living lab workshops, Arsinoe team distills the stakeholders' knowledge and experience on the respective case study around a specific climate change hazard and the risen vulnerabilities and exposures of the affected systems. The objective of this exercise in to create a mental map that represents the collective knowledge and experience of the stakeholders and then use the mental map to calibrate the conceptual model, which constitutes the roadmap for the modelling approach towards the risk assessment. The feedback of the living lab is translated into the fundamental components of the risk assessment approach: a) hazard, b) vulnerability, c) exposure, and d) capacity (UN, OEWG 2016).

Risk: The potential loss of life, injury or destroyed or damaged assets which could occur to a system, society, or a community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity (i.e., Risk = Hazard x Vulnerability x Exposure/Capacity)

Hazard: A process, phenomenon, or human activity, including violent conflict and human rights violations, that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation.

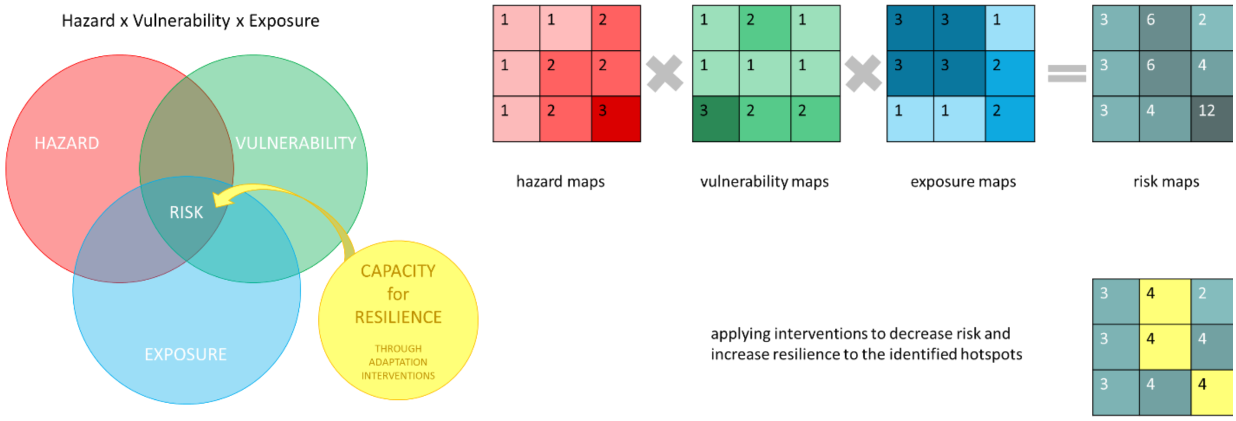
Vulnerability: The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Capacity: The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce risks and strengthen **resilience**.

Figure 3.2 presents a conceptual schematic of an assessment approach for the identification of risk hotspots, where capacity interventions are required in order to increase resilience in a spatiotemporal risk setting, such as this of Athens case study, where the central investigated hazard is extreme heat. Following, in Section 5, this approach is applied for risks identification in the Athens case study (see Section 5.1).

Figure 3.2 The risk assessment approach on identifying hotspots for interventions.

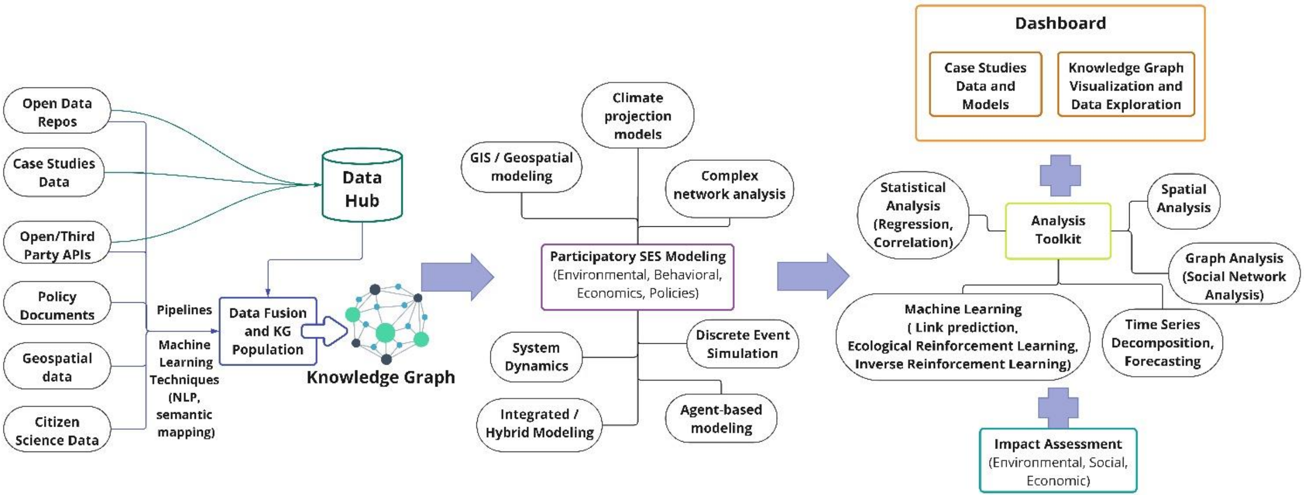


4.0 Knowledge management infrastructure and SES modeling interplay

The availability of knowledge management infrastructure is crucial for facilitating participatory modeling processes for socio-environmental systems because of the intricate and multifaceted nature of these systems, which necessitate contributions and expertise from a diverse range of stakeholders. Knowledge repositories serve as centralized and accessible locations where stakeholders and interdisciplinary scientists can access relevant data, research, and other resources that can aid in the modeling process. Furthermore, they can promote transparency and accountability by enabling them to monitor the sources and quality of information utilized in the modeling effort. Knowledge repositories can foster informed decision-making processes based on evidence-based research and stakeholder input, which ultimately lead to more effective and equitable outcomes for socio-environmental systems.

The knowledge management infrastructure in ARSINOE comes from the developments in WP4 and consists of three main tools, namely the Data Hub, the Knowledge Graph (referred to from now on as SustainGraph) and the Dashboard. Each one of the tools, as well as the overall knowledge management infrastructure, contributes to the various steps of a participatory modeling process. On the other hand, the data collected and/or produced through a participatory modeling process can be fed back to the knowledge infrastructure, enriching the available information and enabling the extraction of insights by data scientists. The Data Hub acts as the main data repository where various datasets of different types and formats (e.g., text documents, time series data, geospatial data) can be hosted and made available to any interested party (e.g., data scientists, environmental scientists, policy makers). SustainGraph acts as a graph database where the data is represented along with their semantics, enabling their unique representation and the tracking of relationships among them. The Dashboard provides nice and intuitive interfaces to end users to easily consume the available information and facilitate knowledge sharing and decision-making processes. The interplay between the knowledge management infrastructure in ARSINOE and the participatory SES modeling processes is depicted in Figure 4.1.

Figure 4.1 Knowledge management infrastructure and participatory modeling process interplay.



The approach is separated into three conceptual parts. The first part regards the conceptualization and continuous population of the Data Hub and the SustainGraph, fusing data coming from a variety of data sources. The second part regards the support of participatory SES modeling to capture systemic changes, taking advantage of the knowledge in the ARSINOE knowledge management infrastructure and the existence of mature modeling techniques. The third part regards the support of a set of analysis processes that can be used to assess the impact of various scenarios, based on the outcomes of the modeling process in the second part.

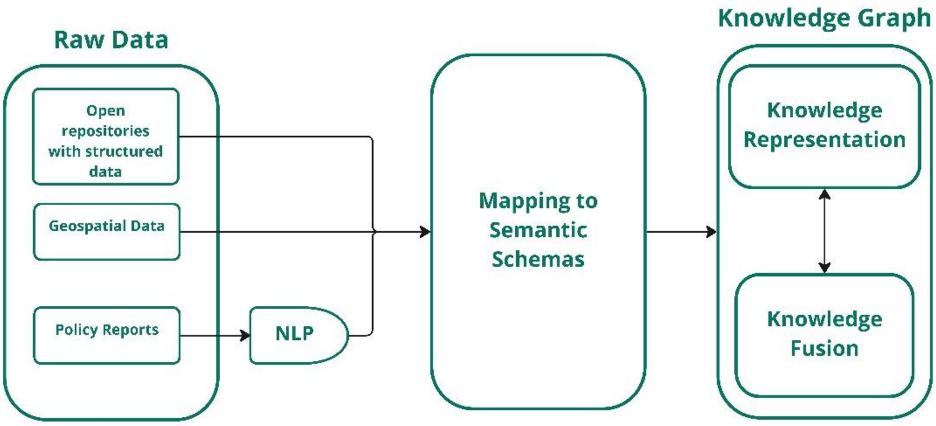
4.1 Data Fusion, Data Hub and Knowledge Graph Population

A Knowledge Graph (KG) is a graphical representation that includes specific knowledge and facts. When we refer to "explicit knowledge," we are discussing the conceptualization of the entities within the KG and their interrelationships. Creating a definition of explicit knowledge is typically the initial stage in developing a KG. To achieve this goal, existing knowledge from ontologies, information models, and taxonomies is used. The explicit knowledge that is depicted within the KG is not fixed, as entities can be added or removed dynamically, and relationships can be created or updated. This is an ongoing process that occurs simultaneously with the population of the KG with instance data.

The data referred to as "facts" can be obtained from various structured, semi-structured, or unstructured sources. Such data is made available in the Data Hub. This data encompasses open and linked data within open data repositories, including time-series data, textual documents, directives, and policies. This data can be accessed via open or third-party APIs, collected from environmental sensing systems such as IoT nodes, gathered from existing organizations and citizens' observatories, retrieved from satellite systems (e.g., images), and obtained through semantic crawling of web resources. In addition to populating the SustainGraph with data coming from the Data Hub, the data can be processed in real-time or accessed directly through open APIs.

The sources of data used to populate the KG and made available in the Data Hub are diverse in terms of origin, structure, volume, and spatial and temporal granularity. To process and integrate them into the KG, a variety of data fusion and homogenization mechanisms can be employed, as shown in Figure 4.2. Data fusion involves processing techniques that improve the quality of aggregated data, such as removing outliers and aggregating data over time or space, as well as techniques for extracting knowledge from the data. Machine learning techniques can be used to identify hidden relationships, support link prediction, and evaluate the validity and strength of continuous links and relationships. Textual data can be subjected to entity recognition through natural language processing techniques, while computer vision techniques can be used to extract knowledge from images.

Figure 4.2 Data Fusion mechanisms.



4.2 Participatory SES Modelling

After creating a unified and comprehensive knowledge graph (KG), participatory modeling of socio-environmental systems (SES) can be carried out. Actually, the KG provides a consistent and rich representation of the collected data, enabling scientists to investigate complex problems resulting from interactions between human and natural systems. The overall knowledge management infrastructure that is developed in ARSINOE can help to tackle part of the challenges for the participatory modeling of SES.

For instance, KGs are powerful tools that can help **bridge epistemologies across different disciplines**. By linking data from different sources, knowledge graphs can provide a unified view of information across different fields, enabling researchers to identify connections and relationships that might otherwise go unnoticed. This can help to break down disciplinary barriers and foster collaboration between researchers from different fields, facilitating the exchange of ideas and knowledge. By making it easier to combine data from different sources and identify patterns and connections, knowledge graphs can also help researchers to develop new insights and theories that cut across different disciplines, leading to more innovative and impactful research outcomes.

The ARSINOE Data Hub and the SustainGraph can help to **manage the sources of uncertainty** in data coming from social, environmental, and economic repositories by providing a framework for representing and linking different types of information. They can help to identify and quantify sources of uncertainty in data, such as missing values or errors, by providing a structured way of representing and analyzing data. By integrating data from different sources, the SustainGraph can also help to identify and manage conflicting or inconsistent information, which is a common source of uncertainty in interdisciplinary research. Additionally, the Data Hub and the SustainGraph can help to track the provenance of data, providing information about where data came from, how it was collected, and how it has been processed, which can help to improve the transparency and reproducibility of research outcomes. Different **data scales** can be captured based on the data population of the Data Hub and the SustainGraph with time series data and spatial data. For such data, the raw information may be made available in existing data repositories, while part of them can be introduced on demand (e.g., through the development of data population pipelines) in the SustainGraph to support analysis processes.

The SustainGraph can also help to **capture systemic changes in socio-environmental systems** by providing a structured representation of the complex interactions and relationships between different elements of the system (e.g., by considering the identified hazards in a specific area; by considering the stakeholders and their areas of financial activity; by considering the mapping of policies documents with the SDGs). By integrating data from different sources and representing it in a consistent and coherent way, it can provide a comprehensive view of the socio-environmental system, including its underlying structure, feedback loops, and interdependencies.

4.3 Analysis Toolkit and Impact Assessment

Researchers will be able to leverage the participatory SES models and the up-to-date information in the KG to gain valuable insights. A diverse set of analysis methods can be utilized for this purpose, including statistical analysis to identify trends and patterns, spatial analysis to explore geographical relationships, graph analysis to analyze the network structure of the data, and time series analysis to examine changes over time. Additionally, supervised and unsupervised ML techniques can be applied to the data to uncover hidden patterns and relationships, classify data, or make predictions. With these powerful analytical tools at their disposal, scientists can more effectively understand and address complex problems arising from the interactions between human and natural systems.

Various analysis techniques can be employed to extract insights from the data and models available in the KG. Pure statistical analysis, for instance, can be used to detect data clusters, classify data into high-level categories, or identify hidden correlations. Spatial analysis, on the other hand, is particularly useful for environmental problems with a clear spatial dimension (Stocks et al.,2000). This type of analysis can track the evolution of environmental phenomena, identify specific locations for objects or events based on well-defined socio-environmental criteria, or survey protected areas that are close to industrial sites. Graph analysis offers a wide range of techniques, including Social Network Analysis (SNA), which can be used to observe social structures through the use of networks and graph theory. SNA can help scientists explain natural resource governance in different settings, examine how decision makers adapt to a changing social and ecological context, and understand the transmission of local ecological knowledge (Salpeteur et al.,2017). Time series decomposition is also a valuable analysis technique as it enables the detection of repeated patterns over time, making it useful for forecasting the future evolution of SES phenomena. Scientists can apply these and other techniques, such as supervised or unsupervised machine learning, to gain a better understanding of complex SES interactions and make informed decisions based on data-driven insights.

The collected data can be analyzed using various machine learning techniques in conjunction with the developed SES models. ML techniques are particularly useful in cases where traditional analysis methods cannot capture the complex relationships between variables. By exploring the data, new knowledge can be generated, and ecological patterns can be recognized and predicted in both space and time. The developed SES models and analysis mechanisms can be used for impact assessment processes. These assessments can include environmental, social, economic aspects, or a combination of them. To facilitate impact assessment, easy-to-understand visualizations can be created to monitor key performance indicators (KPIs) related to different scenarios. Overall, the application of ML techniques can offer a powerful tool for the analysis of the collected data and the development of impactful insights.

5.0 Proof of Concept Participatory SES modeling in ARSINOE

5.1 Interdisciplinary modelling in the Athens case study

5.1.1 Main scope, objectives and participatory processes

In Athens, the ARSINOE case study will concentrate on tackling the impact of Climate Change on both urban biodiversity and public well-being. The focus will be on evaluating the effects of Nature Based Solutions (NBSs) in reducing the Urban Heat Island (UHI) effect in the area. The assessment of adaptation options will involve a multi-criteria analysis, which will consider various factors such as effectiveness, contribution to climate change adaptation, technical and economic feasibility, and public acceptance. To increase public awareness and participation, ARSINOE will adopt three methods: citizen science, youth assemblies to simulate local Green Deal processes and promotion of green practices, and integration of innovation and science into educational curricula.

5.1.2 Conceptual design and analysis processes

The data and model flow diagrams of Figures 5.1, 5.2 and 5.3 are constructed to include the relevant hazard, vulnerability and exposure submodules, the recommended and tested capacity interventions for resilience and the auxiliary layers of data, that are used for the assessment and calibration of the other components. These figures also present the participatory evolution of the modelling structure from an initial preparatory phase, without any inputs by the living lab, to a mature phase with input of two living lab workshops.

Figure 5.1 presents the modeling flow diagram of the initial work hypothesis, constructed collectively by the scientific team for the Athens case study, according to which extreme heat and air pollution are investigated as primary hazards that have cascading effects on morbidity, mortality, and well-being. Relevant research has established since the early 80s links between heatwaves and health (Jones, et al., 1982) and between increased temperature and well-being (Hawkins, 1981). Assessments that relate extreme heat and air pollution to mortality rates exist for the specific case study of Athens (Zafeiratou et al., 2019; Founda, et al., 2022 and Katsouyanni, et al., 2020, respectively). Van der Schriek, et al. (2020) highlight the trade-off of heatwaves and air pollution regarding morbidity, which is also specifically investigated for Athens and for the wider area of the Mediterranean (Founda, et al., 2019). Heatwaves, as defined by the UNDRR hazard taxonomy, as the most neighboring concept to extreme heat events, and their impact on land surface temperature are modeled, through the urban heat island (UHI) phenomenon, as a function of green and grey infrastructure cover, the climate variables, and the expected climate change projections (De Ridder, 2003; Mirzaei, 2015). Air pollution is also assumed to have common predictors with heatwaves (Bertazzon, et al., 2015; Varotsos, et al., 2021). The green infrastructure auxiliary data set is supplemented by a citizen science thread, that specifically builds a tree inventory. Vulnerabilities refer to the related impacts on health and well-being as functions of population vulnerability distribution (age and income) and the exposure refers to residents that are exposed to the two environmental stresses as a function of population density.

Figure 5.1 The initial risk assessment plan.

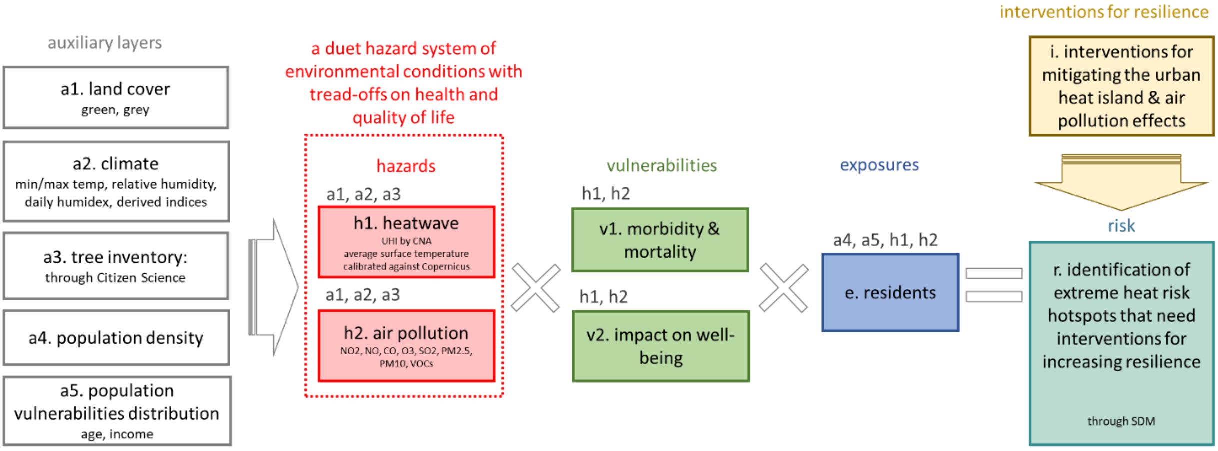


Figure 5.2 presents the modification of the initial plan, after incorporating input of the living lab, after its first workshop. The central topic of the workshop is "extreme heat events". Stakeholders validated the hypothesis and documentation of the scientific team that air pollution should indeed be coupled to extreme heat, regarding the defined vulnerabilities. Additionally, they added two hazards that have significant trade-offs and interdependencies with heatwaves and air pollution. The discontinuity of green areas in the city is also an urban planning induced stress that is causing degradation of a series of layers linked to the well-being of residents, such as the environmental, the cultural, the aesthetics, and the archaeological layers. The multifunctional properties of green connectivity in urban landscape are investigated and acknowledged by Zhang et al., (2019) and Bai (2018). These layers are not only linked to residents' vulnerabilities. Alongside with heatwaves and air pollution, they also have an economic impact on tourism due to the exposure of tourists and businesses. Dube & Nhamo (2020) and Rozbicka & Rozbicki (2021) provide some initial evidence to support the hypothesis of the impact of environmental conditions deterioration on tourism. Workers are identified by the living lab as a group specifically exposed to these hazards. Energy consumption increase caused by air conditioning due to the heatwaves is an impact particularly distinguished by the living lab, but also supported by various research works (Viguié, 2020). Another cascading hazard brought into attention by the living lab is the increase of violence reinforced by the degrading environmental stresses. The hypothesis is also supported by literature with various research works proving correlation of temperature or extreme heat and violence or aggression since the early 80s (Bell, 1981; Harries & Stadler, 1988; Anderson 1989), while recently studies explore the impact that climate change is expected to have on collective violence and aggression (Cane, et al., 2014; Levy et al., 2017; Chersich, 2019). Landscape fragmentation is identified by the scientific team as an auxiliary layer to assess the discontinuity of green. Accessibility to green is introduced as an auxiliary layer to assess the exposures of residents and workers. Energy efficiency of buildings is introduced to assess the vulnerability of energy consumption. Tourist accommodation and businesses distribution in the city can be used for the assessment of tourists and businesses exposures. Additional population vulnerability attributes are added for building more descriptive indexes, such as the social deprivation index, the house ownership, house size and age, profession, nationality and unemployment. Nationality can be used as an index for the migration flow and the relevant vulnerabilities. Regarding the land cover, the living lab brought up the potential importance of blue infrastructure, which might mitigate the hazard of extreme heat locally, and also at a psychological, if not at a bio-physical level. Road network and building heights are also added to the land cover attributes as relevant to the urban heat island. In this workshop, discussion on the geographical boundaries of the case study are also set.

The area of the Hadrian Aqueduct, an ancient roman aqueduct that is discussed to be brought back to use for supplementary urban water supply, especially irrigation of green areas, was noted as an area of extreme importance in relevance to the discussed topics.

Figure 5.2 The risk assessment plan after the first living lab workshop.

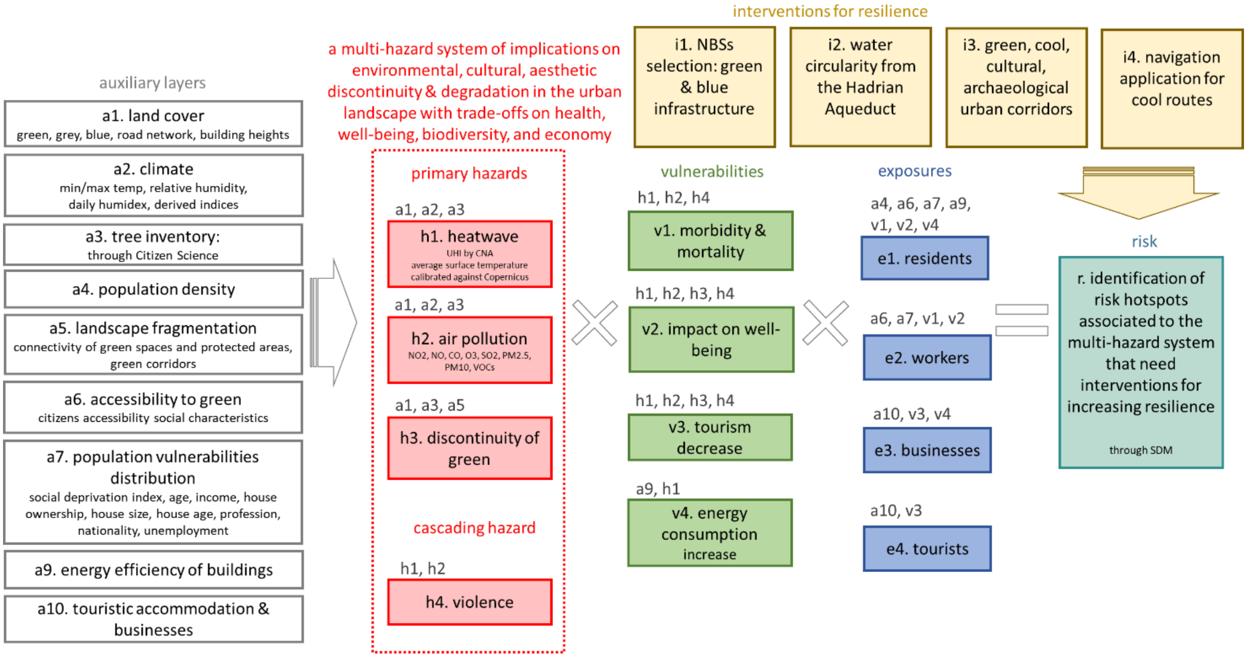


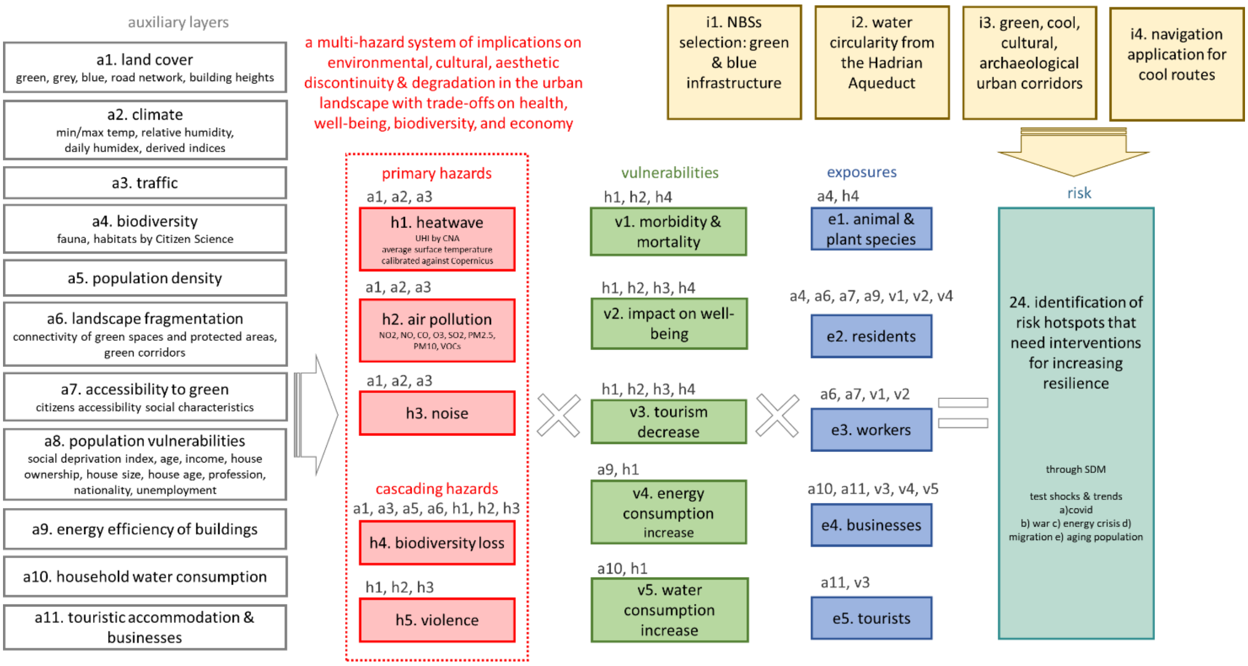
Figure 5.3 presents a more mature modeling and data flow diagram that has occurred after the second living lab workshop. The main objectives of the second workshop with regards to the modeling process are: a) to validate and fine tune the mental map and the conceptual model that have already been constructed and b) to create a collective vision for Athens regarding its resilience capacities against the investigated hazard system. Both objectives' processes feed the modeling flow diagram in two ways: Firstly, they fine tune the definitions and boundaries of the risk system adding and improving the selection of hazards, vulnerabilities, and exposures and, secondly, they add to the solutions perspectives initiating the brainstorming for recommended technical, technological and socio-economic interventions to be tested, expected to reinforce the capacity of the vulnerable systems. The interventions discussion and selection is planned to be initiated in a later phase of the project, however the stakeholders have already been discussing about existing, planned and imagined solutions, giving an initial hint and direction for scenarios to be tested. A major change that occurred in this phase is the realization that green discontinuity is only part of a much wider hazard, that of biodiversity loss. Such a change was depicted based on the collection of ideas, interests and opinions by the stakeholders engaged in the living labs in the Athens case study.

Biodiversity loss is also recognized by the Sendai framework (UNDRR, 2020) as an environmental type and environmental-degradation cluster hazard. Heatwaves, air pollution, and noise share common drivers with habitat loss in the urban setting, such as impervious grey surfaces and green areas fragmentation (Shochat et al., 2010), but also constitute drivers to biodiversity loss themselves (Proppe, et al., 2013; Newport, et al., 2014; Fenoglio et al., 2021).

Biodiversity loss, in this content could as well be classified as a vulnerability, however it is chosen to classify as a hazard with tradeoffs to the primary hazards. The second workshop also added another primary hazard of multiple tradeoffs with the existing hazard system, that of noise (Slabbekoorn, 2019). To the increase of energy consumption, increase of water consumption is also added to the system of vulnerabilities.

Except for the structural interventions of the living lab to the modeling approach, there is also correction of the geographical boundaries of the case study. In the first workshop, the Hadrian Aqueduct was indicated as the heart of the problem, also capable of offering a series of synergies, technical, funding, cultural, administrative and many more. In the second workshop, the boundaries of the case study are extended to include a much wider area to showcase more intense variability regarding the biophysical properties, but also the socio-economic vulnerabilities.

Figure 5.3 The risk assessment plan after the second living lab workshop.



5.1.3 Development status

At the current phase, the main objectives of the case study are clarified and a set of conceptual maps for representing the tackled concepts are produced. Initial modeling work has taken place. Based on the metrics that have to be fed to the analysis processes, data population in the ARSINOE knowledge management infrastructure is taking place. In the upcoming period, the development of analysis processes is going to be realized, while part of such processes will be supported over the SustainGraph to facilitate scientists to execute such processes in an efficient way (e.g., by avoiding the data management overhead).

In the context of the present WP, in an effort to detect and quantitatively evaluate the spatial and temporal patterns related to Urban Heat Island (UHI) effect, an analysis of time series of temperature, humidity, wind speed as well as the land covers and land uses of a region, using mainly complex network analysis based on time series is conducted. The data have been collected from the Copernicus database, for the area of the central region of Athens, point by point in a 100-meter grid. At each point, the temperature, humidity and wind speed have been recorded.

The methodology initially employs the construction of complex networks based on univariate analysis (use of each variable separately: temperature, humidity, and wind speed). The aim of the analysis is to identify the nodes of the network that correspond to points of increased interaction with other points (hubs); the presence of hubs in a system indicates points of importance in the system under study and could be linked to the UHI effect. Next the relationship of such points with land uses and land covers, as well as their spatial location, are explored. Since a hub represents a point of strong interaction such points may also be candidate points for natural green interventions in the frame of the project, since affecting such points a large number of linked points-locations are affected too.

In addition to this approach, using the multilayer network methodology, we construct networks using simultaneously all variables at each point, in such a way that the relationships and interactions between the individual networks (representing properties) can be explored. This type of analysis can reveal non-linear or complex interactions of the various variables with the temperature as well as their spatial location and land use. This analysis applies both to the whole dataset simultaneously, and to individual time series based on their seasonality and periodicity, in order to examine and possibly comment on different results, since the available data have hourly records for a period of six months, from April to in September of four consecutive years.

An important aspect to be investigated is the temporal evolution of the complex networks which can provide important information on the seasonal or time-dependent behavior as well or the effect of an external parameter which will lead to further conclusions. At the same time an alternative strategy to identify specific points and behaviors will be used as a complementary approach. We apply the hierarchical clustering methodology so that time series from different locations are sorted into clusters and then using these subgroups we perform more detailed complex network analysis as described above for the specific series in order to identify more fine scaled dynamics/interactions.

5.2 Interdisciplinary model to support air quality predictions

5.2.1 Main scope, objectives and participatory processes

This modeling effort refers to the participatory development of a model, with the scope to support the numerical predictions of air pollution concentrations over Athens (in the frame of the Athens case study within ARSINOE).

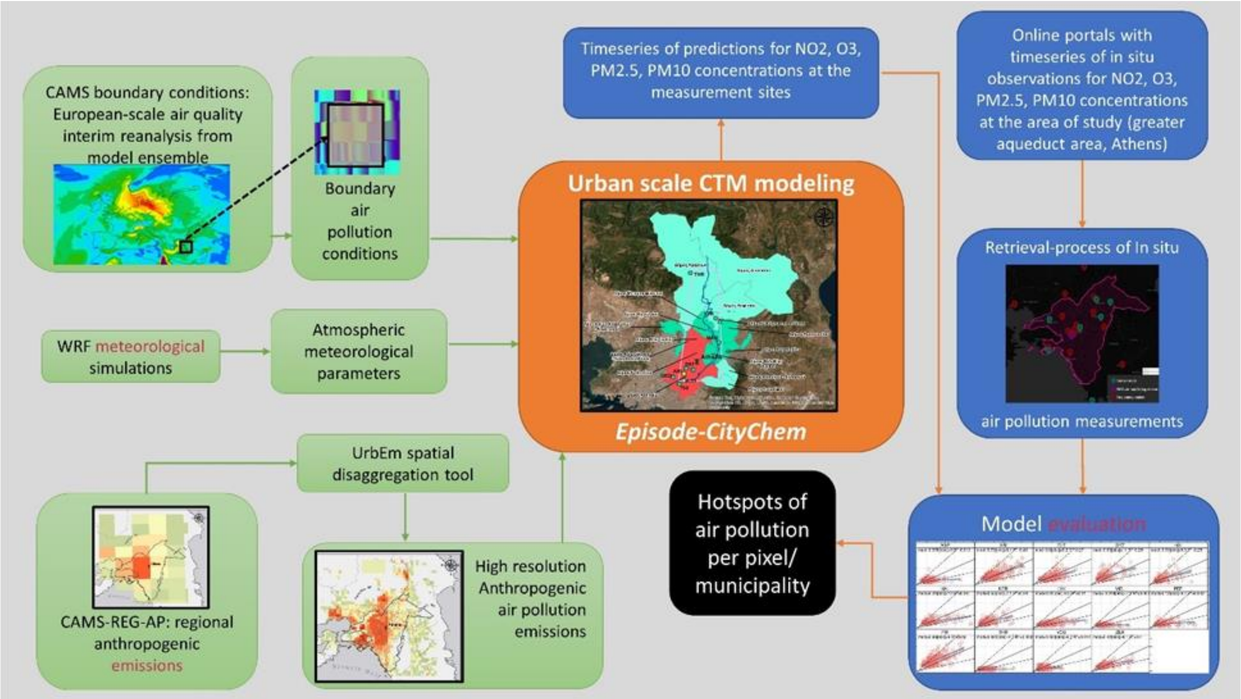
The atmospheric scientists (NOA) have initiated interaction with Information Technology (IT) experts (ICCS), towards the understanding of the needs of the former and the capabilities of the latter, relevant to the known and well-established challenges faced by the numerical atmospheric modelers. In particular, the numerical modeling systems necessitate credible observational timeseries for their accuracy assessment. Access to such time series data can be provided through queries over the data infrastructure made available in the ARSINOE project, where up to date data can be made available for analysis purposes. Thus, easy access to in situ time series data can be provided by automating the procedures for data retrieval and processing and the incorporation of data analysis. Custom visualizations for both the input and the output data for the model can be provided, enabling the atmospheric scientists to get a quick overview of the parameters to be used in the analysis processes. Where applicable, some data analysis pipelines may be also developed and adopted.

So far, interaction among the participants has followed the conventional methods in the form of virtual meetings and exchange of e-mails. The participatory processes are currently being studied so that the most suitable and efficient approach for the structure and scope of the model are selected to support development in the later stages. The applied approach and the produced outcomes are going to be detailed on the revised version of D3.2 by M30 of the project.

5.2.2 Conceptual design and analysis processes

The overall concept of this inter-disciplinary model is to combine targeted IT processes with the atmospheric numerical model system, towards the evaluation of air pollution outputs against in situ measurements (Figure 5.4). To this end, the atmospheric numerical component of the system (green boxes in Figure 5.4) is supported by the IT component of the system (blue boxes in Figure 5.4), towards the evaluated estimation of the air pollution hotspot areas of the case study Athens. Specifically, the set of time series data will be made available by the SustainGraph, while custom queries and Application Programming Interfaces (APIs) will be provided for easily getting access to these data, based on the configuration (e.g., time period, sampling frequency, geolocation characteristics) selected by the atmospheric scientists. The statistical analysis of the comparisons between predictions and observations will be supported by the participatory model under development.

Figure 5.4 The conceptual design of the Inter-disciplinary model to support air quality predictions. The green boxes represent the atmospheric numerical component of the system, while the blue boxes represent the IT component. The outcome is the evaluated estimation of the air pollution hotspot areas (here, of the case study Athens).



5.2.3 Development status

The current development status of the designed model is first the definition of the area of study (here, the greater aqueduct area, Athens) and the period under study (2019). Then, the identification of the atmospheric parameters in need for evaluation (meteorology and air pollution) against the publicly available timeseries of in situ observational data, has been completed.

The identification of the sources of this data (online portals) has also been performed. The portals of national (here, Greece) coverage are located (e.g., Ministry of Environment, National Meteorological Service), in addition to the portals of European coverage (e.g., EEA, NOAA), so that the model can be replicable for any European city of interest. Initial work has taken place for the population of SustainGraph with such data, where challenges for providing access to a plethora of time series and spatial data are identified and tackled. These challenges include the need to manage a large volume of data, as well as the need to develop spatial data management functions to provided aggregated data values for specific regions. The usage of external time series and spatial databases is considered as an option for optimal data storage.

5.3 High resolution climate change projections for the Attica region

5.3.1 Main scope, objectives and participatory processes

The main scope of this modeling procedure is the quantification of human discomfort and its evolution under climate change. Climatic indicators relevant to the urban environment and human health will be calculated. Such indicators include number of days classified according to temperature, as well as discomfort indices utilizing state of the art regional climate model data. Downscaling techniques will be implemented, to obtain the appropriate climatic data for Athens, at a higher horizontal resolution (1km). Additionally, hot spots of extreme temperatures will be identified under current as well different future climatic conditions. Similarly, to the previous model, data population and analysis pipelines are going to be made available in the SustainGraph to support the participatory analysis processes.

5.3.2 Conceptual design and analysis processes

In the framework of this activity daily data from a five-member sub-ensemble of GCM (Global Climate Model)/RCM (Regional Climate Model) couples developed within the EURO-CORDEX initiative will be utilized. More Information on these GCM/RCM couples is provided in Table 5.1. The climatic data are available in the Copernicus Climate Change Service (C3S) Climate Data Store (CDS) for a continuous period ranging from 1950 to 2100. The horizontal resolution of the models is 0.11°, while the simulated data will cover three 20-yr periods: the period 1981–2000, which will be used as the reference period and the future periods 2031– 2050 and 2081-2100. To cover a range of possible futures, three Representative Concentration Pathways (RCPs) will be examined, i.e., **RCP2.6**, **RCP4.5** and **RCP8.5**.

Table 5.1 GCM/RCM couples utilized for the development of high-resolution climate change projections for Attica.

Driving Global Climate Model (realization)	Regional Climate Model	Institute
MPI-ESM-LR (r1i1p1)	RCA4.v1	Swedish Meteorological and Hydrological Institute (SMHI)
HadGEM2-ES (r1i1p1)	RCA4.v1	Swedish Meteorological and Hydrological Institute (SMHI)
HadGEM2-ES (r1i1p1)	RACMO22-E.v2	Royal Netherlands National Meteorological Institute (KNMI)
CNRM-CM5 (r1i1p1)	RACMO22-E.v2	Royal Netherlands National Meteorological Institute (KNMI)
EC-EARTH (r3i1p1)	HIRHAM5.v2	Danish Meteorological Institute (DMI)

Further processing of the climatic data will be performed, and statistical downscaling techniques will be implemented in order to obtain the appropriate climatic data for Attica with a higher horizontal resolution (1km). To this aim, the following steps will be followed:

Step 1: Development of a daily high resolution (1kmx1km) gridded dataset (for the period 1981-2000) based on observations for temperatures (Tmax, Tmin) and relative humidity.

Step 2: Statistical downscaling of the RCM daily model variables to the high-resolution observational grid and implementation of bias correction and disaggregation framework as used in (Varotsos et al., 2022).

Step 3: Calculation of climatic indices, quantification of human discomfort and identification of hot spots of extreme temperatures for the different time frames and scenarios.

Step 4: Identification of regions affected by UHI and quantification of its evolution under different climate change scenarios.

5.3.3 Development status

The high resolution (1kmx1km) gridded dataset (for the period 1981-2000) based on observations for temperatures (Tmax, Tmin) and relative humidity for Attica (step 1) has been developed. The statistical downscaling of climate change projections and the calculation of human discomfort indices is ongoing (steps 2 and 3).

5.4 UHI - Distribution of temperatures and associated factors

5.4.1 Main scope, objectives and participatory processes

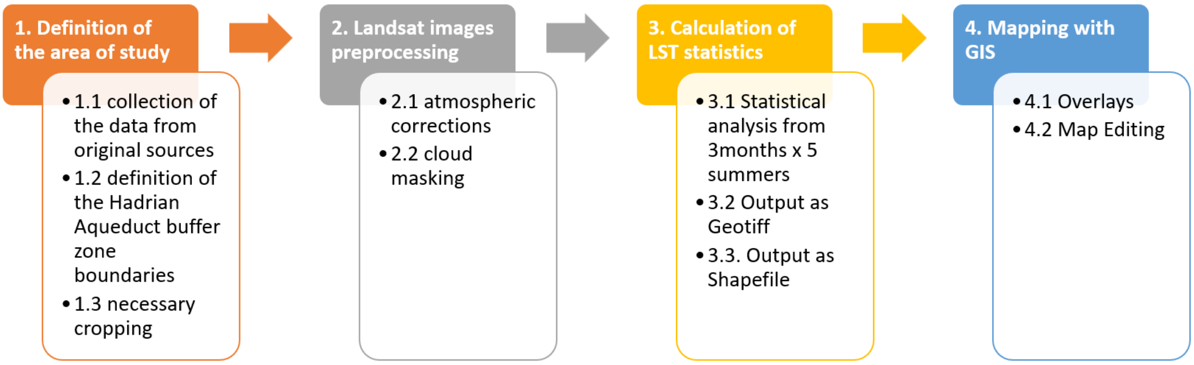
The specific work aims to provide information about the distribution of air and land surface temperatures and the associated parameters like the building heights, land use and tree cover. For the conceptual design for this work, a presentation was provided during the 1st Living Lab in Athens to trigger discussion among participants on the solutions/ interventions. Suggestions and feedback was collected by the participants, that helped us to better formulate the system to be managed.

5.4.2 Conceptual design and analysis processes

The model calculates the mean distribution of summer temperatures for the months June, July and August over five years. It covers the area of Hadrian aqueduct with a buffer zone around it. The data used for the land surface temperature distribution comes from a Landsat satellite (several missions) with a spatial resolution of 100m. The air temperature comes from Copernicus Climate Change Service (C3S) and a climate urban model again using temperatures from 5 summers like before. The difference is that the data comes hourly allowing us to study the diurnal variability of air temperatures within the area of interest. In addition, we have used the Urban Atlas data set from Copernicus Land Monitoring Service (CLMS) and the land use, the street trees, and the building height. We have showcased the hotspots along the Hadrian aqueduct at different times of the day to support mitigation activities. All the codes used for this analysis are developed in house by the National Observatory of Athens/IAASARS (Figure 5.5, 5.6).

Model input parameter(s):	**Source:**	**Resolution:**
Landsat images	https://www.usgs.gov/landsat-missions/landsat-collection-2-level-2-science-products	*30-160m, depending on spectral band and satellite mission*
Urban climate model	*Copernicus C3S*	*100m*
Urban Atlas	*Copernicus CLMS*	*Vector – building block level*

Figure 5.5 The workflow for UHI mapping.



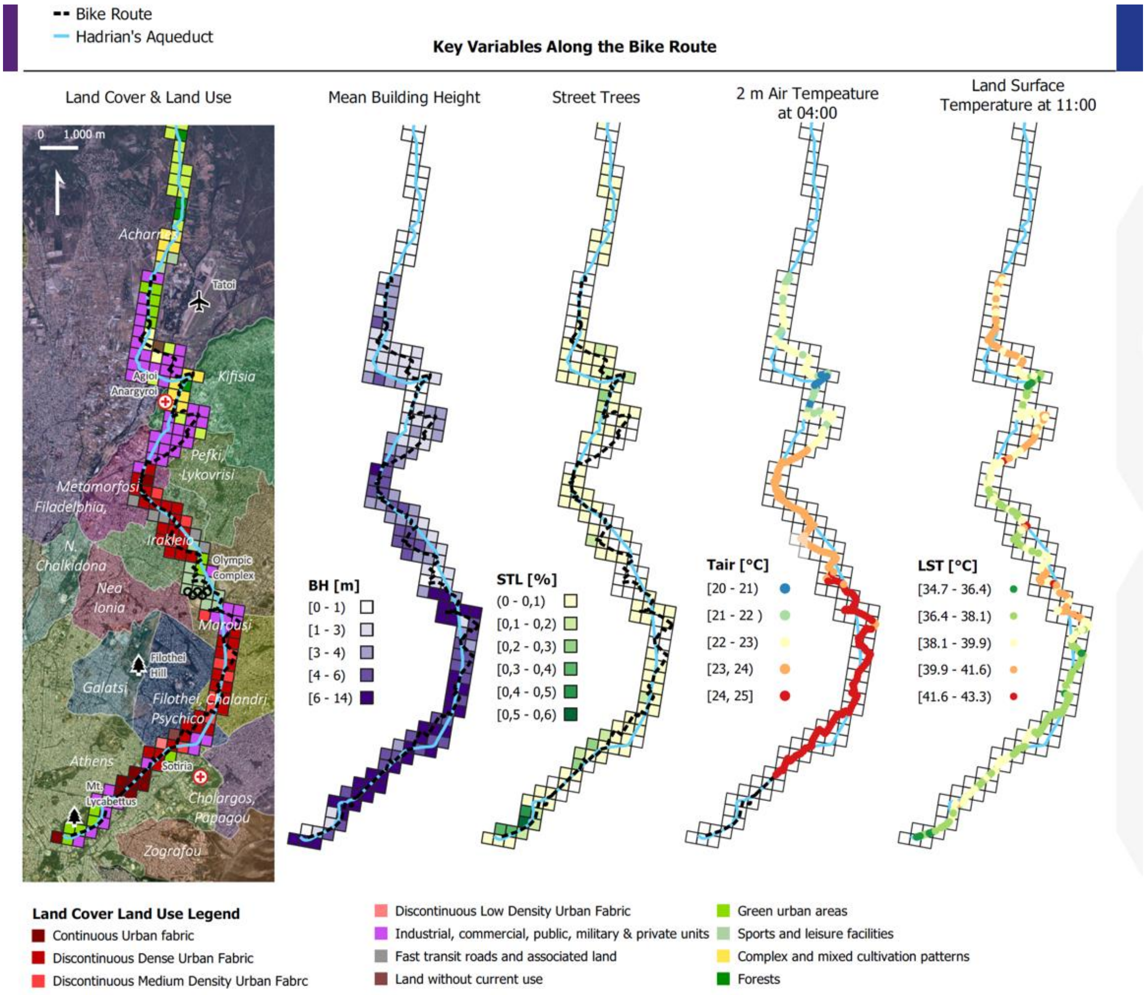
1. Definition of the area of study
- 1.1 collection of the data from original sources
- 1.2 definition of the Hadrian Aqueduct buffer zone boundaries
- 1.3 necessary cropping

2. Landsat images preprocessing
- 2.1 atmospheric corrections
- 2.2 cloud masking

3. Calculation of LST statistics
- 3.1 Statistical analysis from 3months x 5 summers
- 3.2 Output as Geotiff
- 3.3. Output as Shapefile

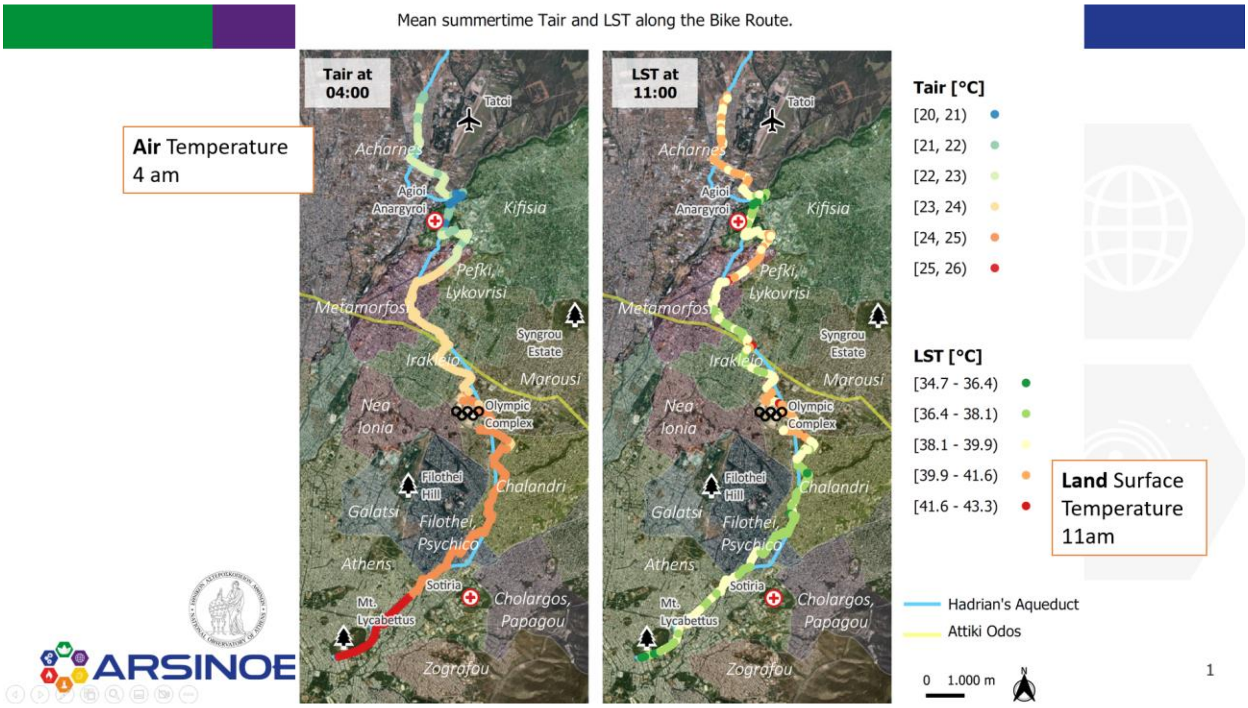
4. Mapping with GIS
- 4.1 Overlays
- 4.2 Map Editing

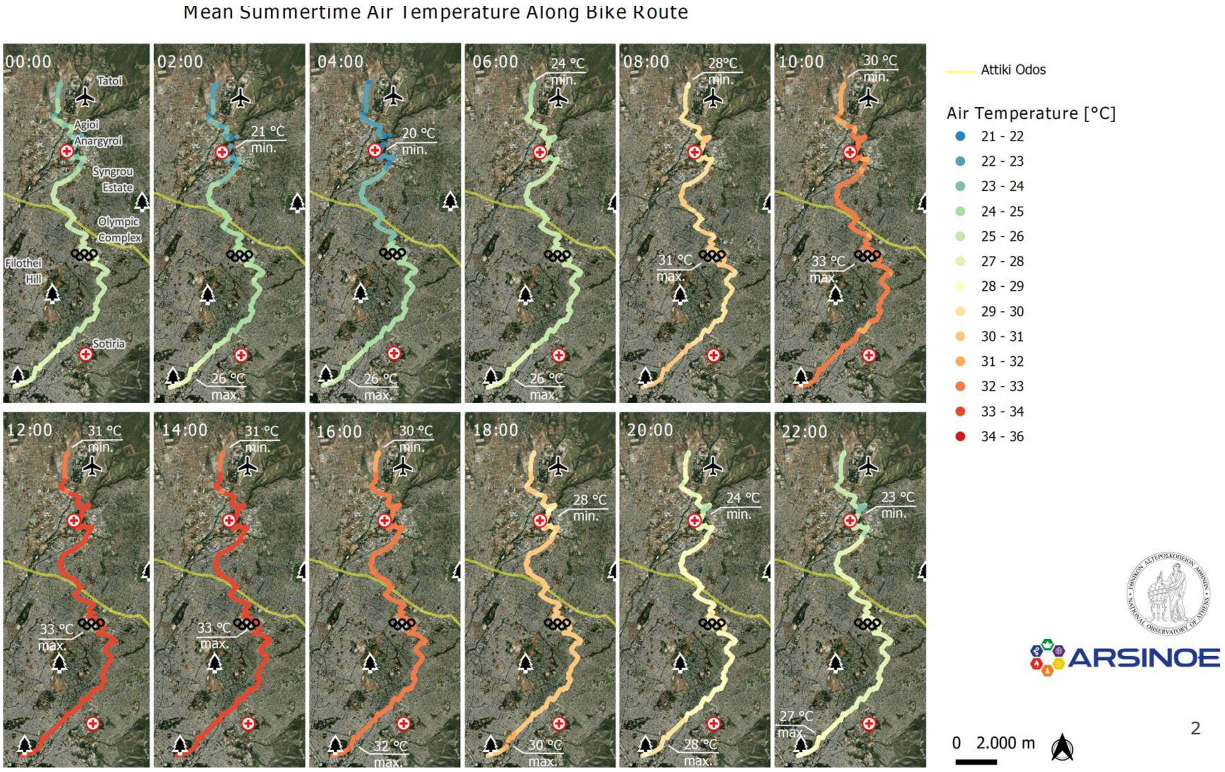
Figure 5.6 The output for Hadrian Aqueduct in AMA.



Tair and LST are the mean summertime Air temperature and Land Surface Temperature at 11:00 Local Time. The source of the LCLU, BH and STL data is the Copernicus Land Service. The source of the Tair data is the Copernicus Climate Service an of the LST data is the National Observatory of Athens.

The model output consists of the following variables: Average Land Surface Temperature; Average hourly Air Temperature; Land Use; Street trees; Building height. All at 100m spatial resilience. The output provides information about UHI and hot spots along the Hadrian Aqueduct in AMA, which is necessary for future planning and urban design and strategic priorities regarding the greening of the city along the aqueduct.





5.4.3 Development status

The development is completed. In the next period a geotiff of summer temperatures for 2 years will be delivered that also includes data from Landsat-9 new NASA satellite. The area of coverage will be the updated case study polygon.

5.5 Connectivity of protected areas – Landscape fragmentation

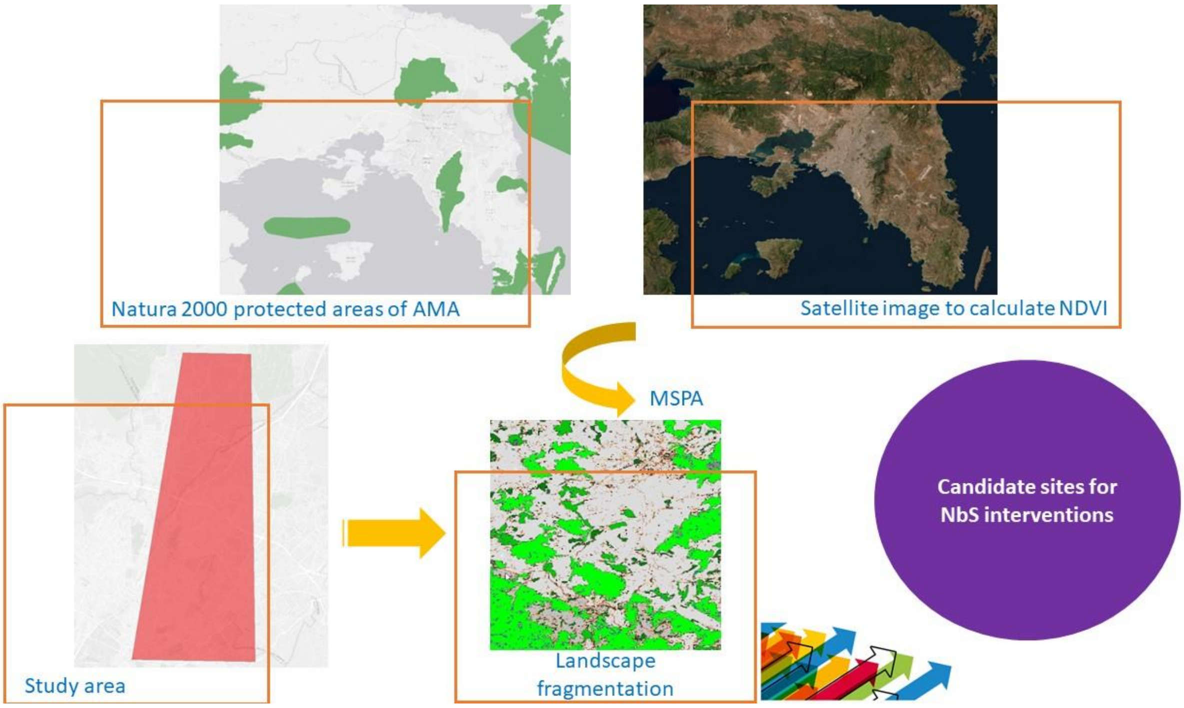
5.5.1 Main scope, objectives and participatory processes

The assessment of the connectivity of protected and green areas in AMA will pave the ground for a coherent nature network, fully complying with the EU Biodiversity Strategy for 2030. In this way, landscape fragmentation for AMA will be assessed.

5.5.2 Conceptual design and analysis processes

The model aims at measuring the connectivity of protected areas and the landscape fragmentation in AMA. The model is a GIS-based toolbox, named GuidosToolbox (Graphical User Interface for the Description of image Objects and their Shapes - GTB) with a wide variety of generic raster image processing routines, including related free software such as GDAL (to process geospatial data and to export them as raster image overlays in Google Earth), and FWTools (pre/post-process and visualize any raster or vector data). The GuidosToolbox Workbench (GWB) contains the most popular image analysis modules set up as command-line-only scripts for automated mass-processing on Linux 64bit servers. The model is performed using ESRI ArcGIS tool (Figure 5.7).

Figure 5.7 The conceptual design of protected areas connectivity.



The analysis includes the following steps:

- definition of protected areas in AMA: overlapping the Natura 2000 network with AMA boundaries the protected areas are geographically identified, along with the most valuable species and habitats according to the 1979 Birds Directive and the 1992 Habitats Directive.

- spatial pattern analysis of AMA's landscape: the model estimates isolated small fragments, core areas, connecting pathways among the landscape of AMA, after calculating the Normalized Difference Vegetation Index (NDVI), thus identifying vegetation greenness and understanding vegetation density and plant health.

- assessing landscape fragmentation in the study area: taking into account the biodiversity status through Natura 2000 protected areas of AMA and the vegetation patterns by NDVI, the Morphological Spatial Pattern Analysis (MSPA) will allow us to evaluate the connectivity of green spaces in the study area and thus recognize fragmented regions, top priority for NbS interventions.

5.5.3 Development status

The identification of protected areas, species and habitats in AMA has already begun. The next step comprises the computation of NDVI, which will lead to MSPA to assess the connectivity of protected areas and the landscape fragmentation in the study area. The final report and the ArcGIS ArcMap document of the connectivity model will be delivered in M24 of the project.

5.6 Accessibility of Green Urban Areas

5.6.1 Main scope, objectives and participatory processes

The concept of 15-minute walking distance will be adopted (PAFI et al., 2022) (Poleman, 2016) (EIT KIC Urban Mobility S.L. ,2022) to investigate if citizens of Athens have access to urban green spaces through pedestrian, citizen-friendly routes. In this way, social inclusion and the connectivity of neighborhoods to green areas will be assessed.

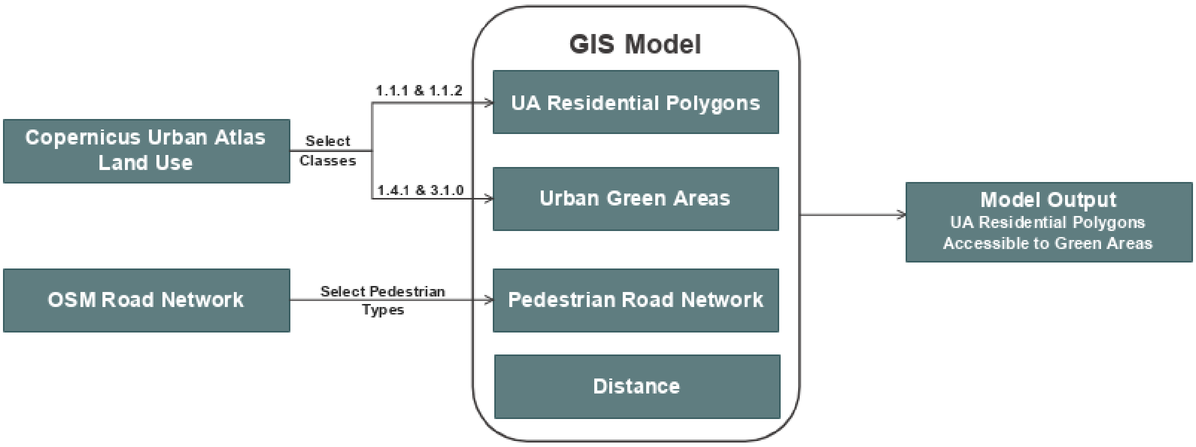
5.6.2 Conceptual design and analysis processes

Before processing, is necessary the preprocessing of the datasets to obtain the final inputs of the model. The main datasets used for this purpose is (i) Urban Atlas (UA) Land Use 2018 and (ii) OpenStreetMap (OSM) Road Network.

UA provides reliable, inter-comparable, high-resolution land use and land cover data with integrated population estimates. The nomenclature includes 17 urban classes and 10 Rural Classes. To define our residential polygons layer, only UA polygons from the classes 1.1.1 and 1.1.2 were selected. For the Urban Green Areas polygons from the classes 1.4.1 and 3.1.0 were selected. For the final Urban Green Areas layer to be created, further effort was put in removing narrow roads or paths inside parks or other urban green areas and calculating the area of each polygon and then buffered at 1.5m.

OSM Road Network parts are tagged based on their road category (motorway, primary, secondary, residential, unclassified, etc.). For our model only pedestrian related tags (pedestrian, living street, etc.) were selected and used as input in our model (Figure 5.8).

Figure 5.8 Data preprocessing as model inputs.

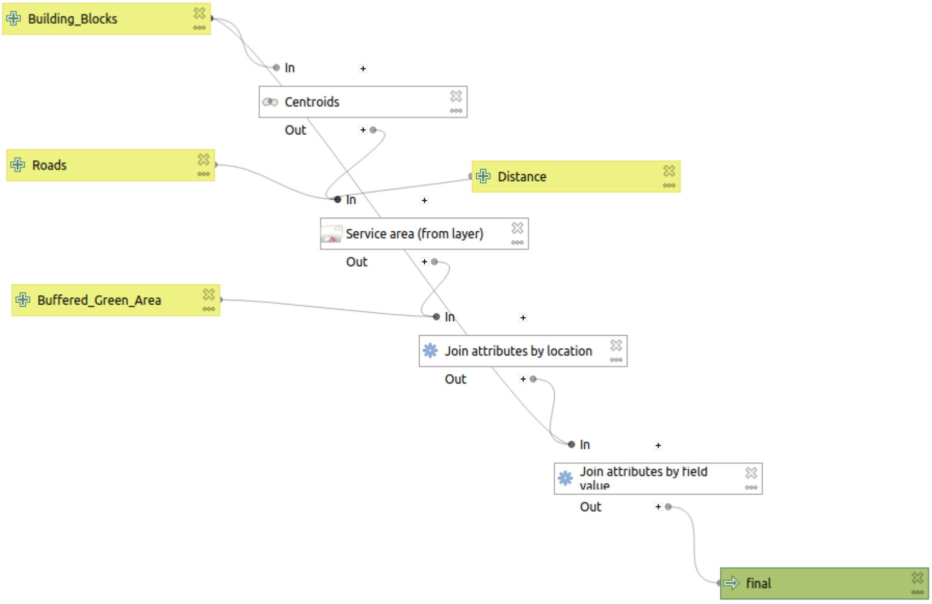


A QGIS model was created that incorporated all the steps of the analysis. The input of the model are the datasets created in the preprocessing stage (UA Residential Polygons, Urban Green Areas, Pedestrian Road Network) as well as the distance (in meters) between the UA Residential Polygons and the accessible Urban Green Areas. The distance was calculated for a 5 minutes and a 15 minute walk with a walking speed of 5km/h.

The main steps of the analysis are:

- Calculating the centroids of each Residential UA polygons
- Executing a Network Analysis to extract the Service Areas of each centroid, namely the part of the road network that can covered in the given distance/time
- Service Areas are spatially joined with the largest intersected Urban Green Area polygon
- Residential UA polygons are joined with the service areas based on a common attribute (UA ID) (Figure 5.9).

Figure 5.9 Model development for the accessibility of Green Urban Areas.



The final output of the model is a vector geopackage file of the UA Residential Polygons with the extra information of the area of the accessible Urban Green Area polygon.

Finally, the output will be combined with additional socio-economic data (population and deprivation index) to examine the spatial correlation of those datasets.

5.6.3 Development status

The next step involves the socio-economic parameters to be calculated and incorporated into the model. The final report and the ArcGIS ArcMap document of the connectivity model will be delivered in M24 of the project.

5.7 Atmospheric numerical model to support microclimatic simulations and nature-based solutions

5.7.1 Main scope, objectives and participatory processes

The application of a numerical model (WRF, description given in section 5.6.2) for weather and microclimate research will provide meteorological output regarding present climatic conditions over the area of study (Athens Metropolitan Area – AMA). Short term and long term, high spatial horizontal resolution (200m) microclimatic simulations will be performed with the aim to validate the outcomes of all the prerequisite Models (1,2,3,4,5) -meaning sites with absence of green urban areas, low urban biodiversity value and air quality, and significant levels of urban thermal stress- and with the ultimate goal to identify sites of AMA that require mitigation/adaptation measures to implement NbS. Specific NbS per site of AMA will be selected based on existing repositories and relevant platforms (e.g., *BISE*, *ClimateScan*, *ClimateADAPT*, *DRMKC*, *Natural Hazards — Nature-based Solutions*, *Nature-based Solutions Initiative platform*, *Naturvation Urban Nature Atlas*, *NWRM*, *OPPLA*, *ThinkNature*, *weADAPT*, *Connecting Nature*, *Global Program on Nature-based Solutions for Climate Resilience*) and/or proposal of new interventions, if needed, according to local characteristics, environmental status and current climatic conditions.

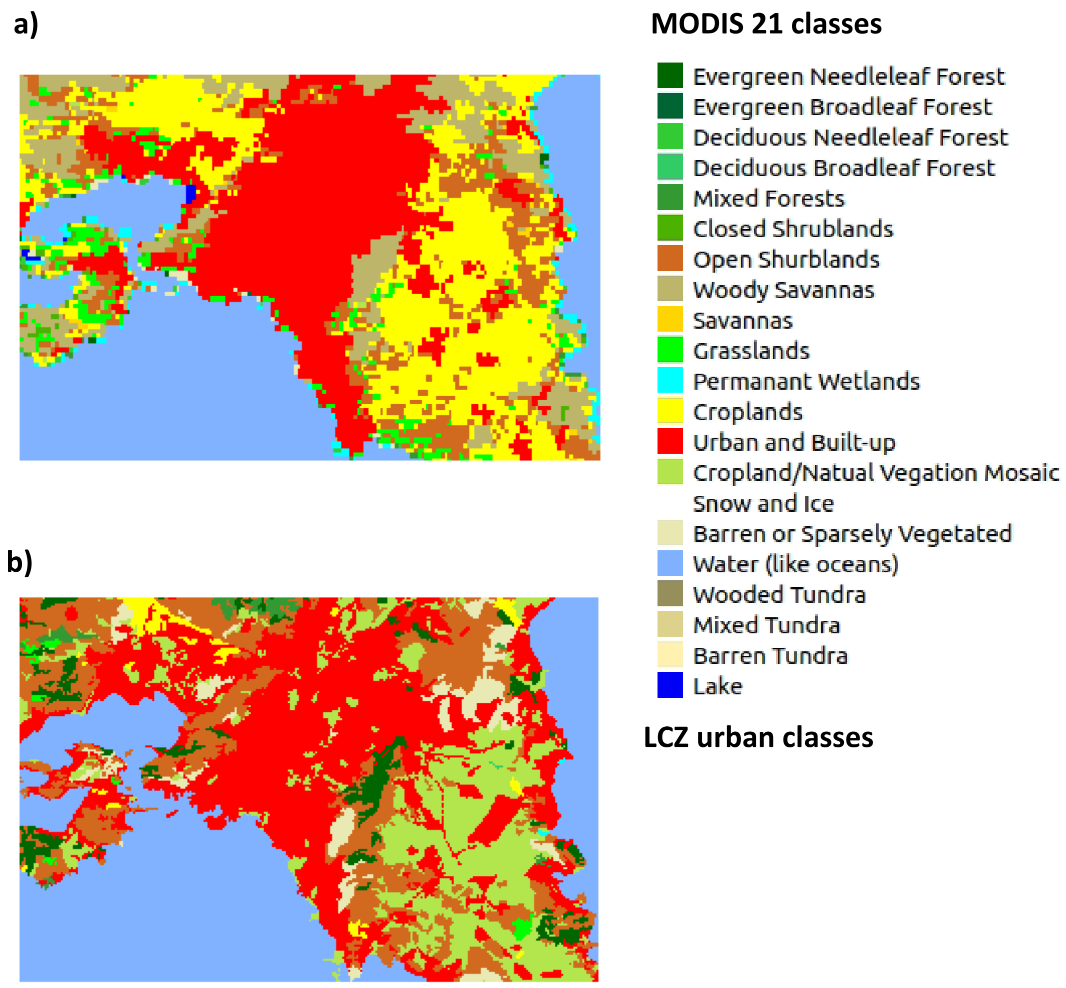
Next, the potential impact of selected NbS on the city's microclimate, such as the enhancement of green and blue infrastructures, will be investigated by simulating different land use scenarios. Model runs need accurate and updated land use, vegetation and soil type input data that will be sourced from the Copernicus Land Service – Pan-European Component. Specifically, Corine Land Cover (CLC) and Urban Land Cover Land Use data (Urban Atlas) will be utilized. The microclimate simulation scenarios will contribute towards testing the effectiveness of NbS, thus concluding on the most suitable NbS to be implemented in each site to improve climate resilience in AMA.

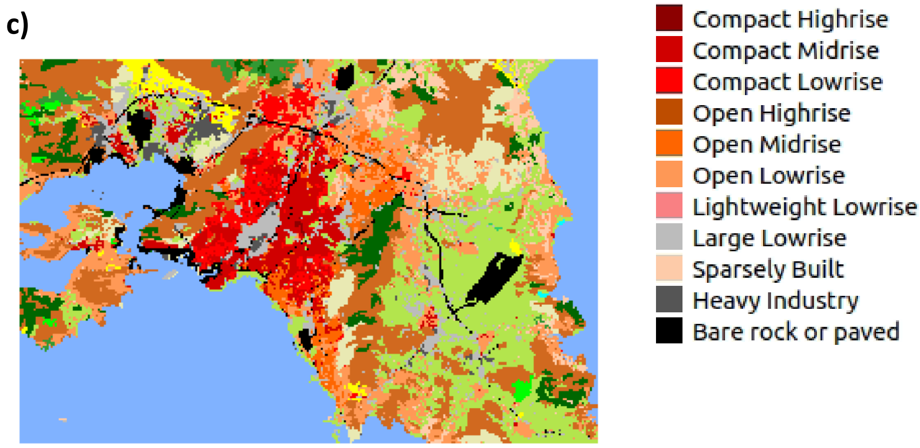
5.7.2 Conceptual design and analysis processes

The Weather Research and Forecasting (WRF) regional model (Version 4.4 (Skamarock et. al, 2021)), is a numerical weather prediction and atmospheric simulation system, which integrates the Advanced Research WRF (ARW) dynamics solver. WRF incorporates the Noah-Multiparameterization Land Surface Model (Noah-MP LSM) allowing the representation of several physical processes, such as canopy radiative transfer with shading geometry considered, separate treatment of the vegetation canopy based on vegetation element density, distribution and crown radius (vertical and horizontal), leaf reflectance and transmittance properties, surface run-off, soil moisture flux, and more. Noah-MP LSM is coupled with the single-layer urban canopy model UCM (Tewari et al., 2007). The single layer UCM uses a simplified two-dimensional urban geometry approach considering building height, roof and road width to represent heat fluxes over impervious surfaces and inside the street canyon environment. It includes trapping/reflection of radiation and shadowing effects defined by the street canyon dimensions and orientation. By computing roof, wall and road surface temperatures and their resulting heat fluxes, it is possible to calculate the energy and momentum transfer between an urban environment and the atmosphere. The coupling of the single-layer UCM with the Noah-MP LSM completes the urban surface energy balance by calculating fluxes from the vegetated portion of the urban surface in a given grid cell. Therefore, the WRF-LSM modelling system allows for a multi-parameter approach when investigating the urban climate in high resolution applications.

Predefined datasets of Moderate Resolution Imaging Spectroradiometer (MODIS) with 21 land use classes and 16 soil categories are generally used by the WRF preprocessor (WPS). At the same time, numerical simulations can also be optimized by ingesting high-resolution vegetation and urban land use data, derived from satellite image analysis, national/European urban databases and land cover databases. To this aim, Corine Land Cover (CLC) and Urban Land Cover Land Use data (Urban Atlas - UA) from Copernicus, will be integrated to the WRF system and a detailed analysis of urban land use categories (UCM model), following the Local Climate Zone (LCZ) classification (Stewart et al., 2012)(Oliveira et al., 2020) will be incorporated to represent the Athens Metropolitan Area in greater detail. In Figure 5.10, the steps of improving land use and land cover in WRF, compared to the default landuse dataset (in this case MODIS 21 class land use data), by ingesting higher resolution (200 m) and updated geospatial data (CLC + UA), is shown. This allows for a detailed analysis of the city's microclimate under current conditions and at the same time it will facilitate the implementation of urban planning mitigation scenarios (e.g., increase of urban green and water bodies, green roofs, use of reflective materials). The impact of the urban solutions proposed, will be quantified by contrasting the model's output between the simulated current conditions and the mitigation scenarios (e.g., differences in surface temperature, air temperature, humidity).

Figure 5.10 WRF simulation domain (200m horizontal resolution) depicting the optimization steps for land use and land cover representation, beginning from the default MODIS 15s resolution data (a), followed by the ingestion of Corine Land Cover reclassified to the MODIS categorization (b) and the ingestion of Urban Atlas urban land use under the Local Climate Zone (LCZ) urban classification (c). MODIS and LCZ categories are described in the attached legend.





5.7.3 Development status

Currently, the ingestion of improved land use and land cover for urban and non-urban areas over the region of interest, has been completed. Additionally, a series of preliminary simulations have been carried out (at NOA's server) to test the robustness of the model's configuration. Next steps include the designing of the urban land use scenarios and their implementation through the microclimatic simulations. Also, the WRF modelling system will be ported to the high-performance computing facilities (HPC) of GRNET (National Infrastructures for Research and Technology) for further testing and to facilitate the computationally demanding numerical applications. Next, simulations of the city's current microclimate will be validated against available meteorological observations and the modelling system will be optimized accordingly before proceeding with the final production runs and output analysis.

6.0 Conclusions and upcoming work

In conclusion, participatory design of socio-environmental systems is a challenging task that requires careful consideration of various factors. The challenges faced include issues related to stakeholder engagement, data availability, communication, and coordination. Overcoming these challenges requires a robust methodology that can support participatory modeling of socio-environmental systems. The methodology should be able to facilitate collaboration among stakeholders, integrate different types of data, and provide a platform for stakeholders to share their perspectives and insights.

The methodology proposed in this document aims to support participatory modeling of socio-environmental systems. It comprises of several steps, including scoping, stakeholder identification, data collection, model development, validation, and communication. Each step is designed to address specific challenges and ensure that stakeholders are involved throughout the modeling process. The knowledge management infrastructure that is developed in the ARSINOE project is exploited in the various steps. The methodology has been applied for the development of initial version of socio-environmental models, and the initial feedback shows that it can effectively support participatory modeling of socio-environmental systems.

The proof-of-concept participatory models presented in this document demonstrate the potential of the methodology to support participatory design of socio-environmental systems. The models cover different socio-environmental systems, including natural resource management, urban planning, and disaster risk reduction. The models showcase how stakeholders' inputs can improve the accuracy and relevance of the models, leading to better-informed decision-making. The participatory models can also help build trust and foster collaboration among stakeholders, leading to more sustainable and equitable socio-environmental systems.

In the following months, the presented methodology is going to be further evaluated and validated, while appropriate re-adjustments may take place, taking into account the feedback received by the various partners. In parallel, the detailed models are going to be further evolved and analyzed, leading to results and insights per the challenge tackled in each case. An updated version of this deliverable is going to be provided by the M30 of the ARSINOE project (March 2024).

References

Anderson, C. A. (1989). Temperature and aggression: ubiquitous effects of heat on occurrence of human violence. Psychological bulletin, 106(1), 74.

Bai, X. (2018). Advance the ecosystem approach in cities. Nature, 559(7712), 7–7. doi:10.1038/d41586-018-05607-x

Bell, P. A. (1981). Physiological, comfort, performance, and social effects of heat stress. Journal of Social Issues, 37(1), 71-94.

Bertazzon, S., Johnson, M., Eccles, K., & Kaplan, G. G. (2015). Accounting for spatial effects in land use regression for urban air pollution modeling. Spatial and spatio-temporal epidemiology, 14, 9-21.

Cane, M. A., Miguel, E., Burke, M., Hsiang, S. M., Lobell, D. B., Meng, K. C., & Satyanath, S. (2014). Temperature and violence. Nature Climate Change, 4(4), 234-235.

Chersich, M. F., Swift, C. P., Edelstein, I., Breetzke, G., Scorgie, F., Schutte, F., & Wright, C. Y. (2019). Violence in hot weather: Will climate change exacerbate rates of violence in South Africa?. South African Medical Journal, 109(7), 447-449.

De Ridder, K., Maiheu, B., Lauwaet, D., Daglis, I. A., Keramitsoglou, I., Kourtidis, K., ... & Paganini, M. (2016). Urban heat island intensification during hot spells—The case of Paris during the summer of 2003. Urban Science, 1(1), 3.

Dube, K., & Nhamo, G. (2020). Evidence and impact of climate change on South African national parks. Potential implications for tourism in the Kruger National Park. Environmental Development, 33, 100485.

EIT KIC Urban Mobility S.L. (2022). Urban Mobility Next 9: ±15-Minute City: Human-centred planning in action Mobility for more liveable urban spaces.

Elsawah, S., Filatova, T., Jakeman, A. J., Kettner, A. J., Zellner, M. L., Athanasiadis, I. N., Hamilton, S. H., Axtell, R. L., Brown, D. G., Gilligan, J. M., Janssen, M. A., Robinson, D. T., Rozenberg, J., Ullah, I. I. T., & Lade, S. J. (2020). Eight grand challenges in socio-environmental systems modeling. Socio-Environmental Systems Modelling, 2, 16226. https://doi.org/10.18174/sesmo.2020a16226

Fenoglio, M. S., Calviño, A., González, E., Salvo, A., & Videla, M. (2021). Urbanisation drivers and underlying mechanisms of terrestrial insect diversity loss in cities. Ecological Entomology, 46(4), 757-771.

Fotopoulou, E., Mandilara, I., Zafeiropoulos, A., Laspidou, C., Adamos, G., Koundouri, P., Papavassiliou, S. (2022). SustainGraph: A knowledge graph for tracking the progress and the interlinking among the sustainable development goals' targets. Frontiers in Environmental Science (10). https://www.frontiersin.org/articles/10.3389/fenvs.2022.1003599

Founda, D., Katavoutas, G., Pierros, F., & Mihalopoulos, N. (2022). The extreme heat wave of summer 2021 in Athens (Greece): cumulative heat and exposure to heat stress. Sustainability, 14(13), 7766.

Founda, D., Varotsos, K. V., Pierros, F., & Giannakopoulos, C. (2019). Observed and projected shifts in hot extremes' season in the Eastern Mediterranean. Global and Planetary Change, 175, 190-200.

Gotts, N. M., van Voorn, G. A., Polhill, J. G., de Jong, E., Edmonds, B., Hofstede, G. J., & Meyer, R. (2019). Agent-based modelling of socio-ecological systems: Models, projects and ontologies. Ecological Complexity, 40, 100728. https://doi.org/10.1016/j.ecocom.2018.07.007

Harries, K. D., & Stadler, S. J. (1988). Heat and Violence: New Findings from Dallas Field Data, 1980–1981 1. Journal of Applied Social Psychology, 18(2), 129-138.

Hawkins, L. H. (1981). The influence of air ions, temperature and humidity on subjective wellbeing and comfort. Journal of Environmental Psychology, 1(4), 279-292.

Jones, T. S., Liang, A. P., Kilbourne, E. M., Griffin, M. R., Patriarca, P. A., Wassilak, S. G. F., ... & Thacker, S. B. (1982). Morbidity and mortality associated with the July 1980 heat wave in St Louis and Kansas City, Mo. Jama, 247(24), 3327-3331.

Katsouyanni, K., Samoli, E., Zafeiratou, S., Stergiopoulou, A., Kasdagli, M., & Evangelopoulos, D. (2020, October). Burden of air pollution exposure on mortality and hospital admissions in Greece by region and urbanization level Burden of air pollution exposure on mortality and hospital admissions in Greece by region and urbanization level. In ISEE Conference Abstracts (Vol. 2020, No. 1).

Lee, K., Rucker, M., Scherer, W. T., Beling, P. A., Gerber, M. S., & Kang, H. (2017). Agent-based model construction using inverse reinforcement learning. In 2017 Winter Simulation Conference (WSC) (pp. 1264-1275). https://doi.org/10.1109/WSC.2017.8247957

Levy, B. S., Sidel, V. W., & Patz, J. A. (2017). Climate change and collective violence. Annual Review of Public Health, 38, 241-257.

Martin, R., & Schluter, M. (2015). Combining system dynamics and agent-based modeling to analyze social-ecological interactions—an example from modeling restoration of a shallow lake. Frontiers in Environmental Science, 3, 66. https://doi.org/10.3389/fenvs.2015.00066

Mirzaei, P. A. (2015). Recent challenges in modeling of urban heat island. Sustainable cities and society, 19, 200-206.

Newport, J., Shorthouse, D. J., & Manning, A. D. (2014). The effects of light and noise from urban development on biodiversity: Implications for protected areas in Australia. Ecological Management & Restoration, 15(3), 204-214.

OEWG 2016: Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction, A/71/644, United Nations, New York (2016)

Oliveira, A., Lopes, A., & Niza, S. (2020). Local climate zones datasets from five Southern European cities: Copernicus based classification maps of Athens, Barcelona, Lisbon, Marseille and Naples. Data in Brief, 31, 105802. https://doi.org/10.1016/j.dib.2020.105802

PAFI, M., SIRAGUSA, A., FERRI, S., & HALKIA, M. (2022). Measuring the Accessibility of Urban Green Areas. A comparison of the Green ESM with other datasets in four European cities (EUR 28068 EN). https://doi.org/10.2788/279663

Palmer, M. (2022). System Archetypes for Understanding and Solving Sustainability Problems. SESYNC

Poleman, H. (2016). A walk to the park?-assessing access to green urban areas in Europe's cities. European Commission, Brussels.

Proppe, D. S., Sturdy, C. B., & St. Clair, C. C. (2013). Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. Global change biology, 19(4), 1075-1084.

Quimby, B., & Beresford, M. (2023). Participatory Modeling: A Methodology for Engaging Stakeholder Knowledge and Participation in Social Science Research. Field Methods, 35(1), 73–82. https://doi.org/10.1177/1525822X221076986

Rozbicka, K., & Rozbicki, T. (2021). Long-term variability of bioclimatic conditions and tourism potential for Warsaw agglomeration (Poland). International Journal of Biometeorology, 65(9), 1485-1495.

Salpeteur, M., Calvet-Mir, L., Diaz-Reviriego, I., & Reyes-García, V. (2017). Networking the environment: social network analysis in environmental management and local ecological knowledge studies. Ecology and Society, 22(1). The Resilience Alliance. https://doi.org/10.5751/ES-08790-220141.

Shin, Y., Lacasse, K., Gross, L. J., & Beckage, B. (2022). How coupled is coupled human-natural systems research? Ecology and Society, 27(3), 4. https://doi.org/10.5751/ES-13228-270304

Shochat, E., Lerman, S. B., Anderies, J. M., Warren, P. S., Faeth, S. H., & Nilon, C. H. (2010). Invasion, competition, and biodiversity loss in urban ecosystems. BioScience, 60(3), 199-208.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Liu, Z., Berner, J., ... Huang, X.-Y. (2021). A Description of the Advanced Research WRF Model Version 4.3 (No. NCAR/TN-556+STR). National Center for Atmospheric Research. https://doi.org/10.5065/1dfh-6p97

Slabbekoorn, H. (2019). Noise pollution. Current Biology, 29(19), R957-R960.

Stave, K. (2010). Participatory system dynamics modeling for sustainable environmental management: Observations from four cases. Sustainability, 2(9), 2762-2784.

Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. Bulletin of the American Meteorological Society, 93, 1879-1900. https://doi.org/10.1175/BAMS-D-11-00019.1

Stocks, C. E., & Wise, S. (2000). The role of GIS in environmental modelling. Geographical and Environmental Modelling, 4(2), 219-235. https://doi.org/10.1080/713668590.

Tewari, M., Chen, F., Kusaka, H., & Miao, S. (2007). Coupled WRF/Unified Noah/Urban-Canopy Modeling System. National Center for Atmospheric Research. http://www.ral.ucar.edu/research/land/technology/urban/WRF-LSMUrban.pdf

UNDRR, Hazard Definition & Classification Review, Technical Report, 2020, United Nations.

van der Schriek, T., Varotsos, K. V., Giannakopoulos, C., & Founda, D. (2020). Projected future temporal trends of two different urban heat islands in Athens (Greece) under three climate change scenarios: a statistical approach. Atmosphere, 11(6), 637.

Varotsos, C. A., Mazei, Y., Saldaev, D., Efstathiou, M., Voronova, T., & Xue, Y. (2021). Nowcasting of air pollution episodes in megacities: A case study for Athens, Greece. Atmospheric Pollution Research, 12(7), 101099.

Varotsos, K. V., Dandou, A., Papangelis, G., Roukounakis, N., Kitsara, G., Tombrou, M., & Giannakopoulos, C. (2022). Using a new local high resolution daily gridded dataset for Attica to statistically downscale climate projections. Climate Dynamics, 1-26.

Viguié, V., Lemonsu, A., Hallegatte, S., Beaulant, A. L., Marchadier, C., Masson, V., ... & Salagnac, J. L. (2020). Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris. Environmental Research Letters, 15(7), 075006.

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., Prell, C., Zellner, M., Paolisso, M., Jordan, R., Sterling, E., Olabisi, L. S., Giabbanelli, P. J., Sun, Z., Le Page, C., Elsawah, S., BenDor, T. K., Hubacek, K., Laursen, B. K., Jetter, A., Basco-Carrera, L., Singer, A., Young, L., Brunacini, J., & Smajgl, A. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. Environmental Modelling & Software, 109, 232-255. https://doi.org/10.1016/j.envsoft.2018.08.028

Will, M., Groeneveld, J., Frank, K., & Muller, B. (2020). Combining social network analysis and agent-based modelling to explore dynamics of human interaction: A review. Socio-Environmental Systems Modelling, 2, 16325. https://doi.org/10.18174/sesmo.2020a16325

Zafeiropoulos, A., Fotopoulou, E., & Papavassiliou, S. (2021). Participatory Socio-Environmental Systems Modeling over Knowledge Graphs. In 2021

IEEE Globecom Workshops (GC Wkshps) (pp. 1-6). Madrid, Spain. doi: 10.1109/GCWkshps52748.2021.9682047

Zhang, Z., Meerow, S., Newell, J. P., & Lindquist, M. (2019). Enhancing landscape connectivity through multifunctional green infrastructure corridor modeling and design. Urban forestry & urban greening, 38, 305-317.

Systems Innovation Approach (SIA) addresses the growing complexity, interdependencies and interconnectedness of modern societies and economies, focusing on the functions of the cross-sectoral system as a whole and on the variety of actors. The Climate Innovation Window (CIW) is the EU reference innovations marketplace for climate adaptation technologies. ARSINOE shapes the pathways to resilience by bringing together SIA and CIW, to build an ecosystem for climate change adaptation solutions. Within the ARSINOE ecosystem, pathways to solutions are co-created and co-designed by stakeholders, who can then select either existing CIW technologies, or technologies by new providers (or a combination) to form an innovation package. This package may be designed for implementation to a specific region, but its building blocks are transferable and re-usable; they can be re-adapted and updated. In this way, the user (region) gets an innovation package consisting of validated technologies (expanding the market for CIW); new technologies implemented in the specific local innovation package get the opportunity to be validated and become CIW members, while the society (citizens, stakeholders) benefits as a whole. ARSINOE applies a three-tier, approach: (a) using SIA it integrates multi-faceted technological, digital, business, governance and environmental aspects with social innovation for the development of adaptation pathways to climate change for specific regions; (b) it links with CIW to form innovation packages by matching innovators with end-users/regions; (c) it fosters the ecosystem sustainability and growth with cross-fertilization and replication across regions and scales, at European level and beyond, using specific business models, exploitation and outreach actions. The ARSINOE approach is show-cased in nine widely varied demonstrators, as a proof-of-concept with regards to its applicability, replicability, potential and efficacy.

ARSINOE

CLIMATE-RESILIENT REGIONS THROUGH SYSTEMIC SOLUTIONS AND INNOVATIONS

This project has received funding from the European Union’s Horizon 2020 innovation action programme under grant agreement 101037424.