NOVA SCHOOL OF SCIENCE & TECHNOLOGY
DEPARTMENT OF PHYSICS

BÁRBARA RAFAEL GAMBOA PAIS
Bachelor of Science in Biomedical Engineering

EVIDENCE-BASED DECISION SUPPORT SYSTEM FOR HEALTH-CLIMATE CRISIS PREPAREDNESS

A HEATWAVE SITUATION ROOM

MASTER IN BIOMEDICAL ENGINEERING
NOVA University Lisbon
October, 2023

NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

DEPARTMENT OF
PHYSICS

EVIDENCE-BASED DECISION SUPPORT SYSTEM FOR HEALTH-CLIMATE CRISIS PREPAREDNESS

A HEATWAVE SITUATION ROOM

BÁRBARA RAFAEL GAMBOA PAIS

Bachelor of Science in Biomedical Engineering

Adviser: Luís Velez Lapão
Professor, NOVA University Lisbon

Co-adviser: Ana Sofia Matos
Associate Professor, NOVA University Lisbon

Examination Committee

Chair: Ricardo Nuno Pereira Verga e Afonso Vigário
Associate Professor, NOVA SST

Rapporteur: Marília Raquel Bettencourt Silva Paulo
Associate Professor, NOVA NMS

MASTER IN BIOMEDICAL ENGINEERING

NOVA University Lisbon
October, 2023

Evidence-Based Decision Support System for Health-Climate Crisis Preparedness
A Heatwave Situation Room

This document was created with the (pdf/Xe/Lua)LaTeX processor and the NOVAthesis template (v6.10.17) [1].

Acknowledgements

My academic journey has been meaningful, made all the more special by the incredible people who have been by my side and to whom I now express my deepest gratitude.

First and foremost, I thank my academic supervisor, Professor Luís Velez Lapão, for his encouragement and expertise and for giving me the opportunity to take part in such a meaningful and challenging project. I can only hope that the work developed reaches all our expectations and performs its groundbreaking techniques to improve Portuguese Healthcare. I would also like to thank all the members of the Digital & Smart Health Care Laboratory for their constant availability to support my work and for teaching me so much. Finally, I would like to thank Ricardo Deus (IPMA), Fernanda Carvalho (IPMA), Dr. Pedro Pinto Leite (DGS), Daniela Freitas (DGS) and José Machado (APA), for the collaboration in providing data and guidance for this dissertation.

I would like to convey my appreciation to all the people who crossed my life over the last five years. In FCT, Ulm and Just a Change, I had the opportunity to meet extraordinary friends and can't wait to see where we all end up.

To Adriana, Afonso, Bea Silva, Bea Lemos, Carolina, Boa-Fé, Patrão, Leonor, Luísa, Maria, Margarida, Baptista, Lopes, Neves and Tiago, there are no other people I would rather have had as my closest friends throughout college. Thank you for all the trips, all the laughs and all the support. To Lisboa and Faneca, words can not express our connection and how sincere and unapologetic we can be with one another. To the family away from home, Mariana, Rui, Margarida and Daniela, thank you for always having a kind word or a tight hug. To Pedro, I'm lucky to have you as a confidant.

Ao Francisco, o meu maior obrigada por seres o meu porto seguro. Que todos os nossos sonhos se concretizem.

Gostaria de agradecer à minha família por estarem sempre presentes e sempre me terem permitido voar tão alto quanto possível, sem nunca ter de me preocupar com a queda. Tenho um orgulho desmedido em cada um de vós. Ao meu avô por me fazer sempre sorrir e à minha avó que me ensina um pouco mais todos os dias. À minha irmã por ser a minha maior apoiante, por acreditar sempre em mim e por ser a melhor amiga que podia pedir. Ao meu pai, por ser o meu maior exemplo de resiliência e dedicação, por todos os dias me incentivar a ser eu própria sem o peso que por vezes coloco em mim mesma e por me ter mostrado o que é a engenharia. Por fim, agradeço à minha mãe, por ser o maior exemplo que poderia ter e a mulher mais inteligente que alguma vez conheci. Obrigada por todos os dias veres em mim o que não vejo e estares sempre disponível para me ajudar em absolutamente todas as áreas da vida. Só posso esperar um dia vir a ser metade do que és.

“***aut viam inveniam aut faciam.”***

“ - i will either find a way or i will make one”

— Hannibal

Abstract

As climate crises intensify, the need for effective public health preparedness becomes increasingly critical. This master's dissertation introduces a comprehensive approach to address this challenge by developing and implementing an evidence-based decision support system. With a focus on heatwaves as a specific scenario, this research combines expertise in biomedical engineering, data science, and public health management.

The research is based on an extensive literature review and a realistic heatwave scenario constructed for the Lisbon and Tagus Valley region in July 2025. The exercise is set to simulate a seven-day heatwave in July 2025, featuring maximum temperatures exceeding 40ºC for seven consecutive days, along with various alarming factors and their impact on healthcare facilities. Diverse public health datasets from various Portuguese sources are aggregated and correlated, and machine learning models are trained to predict public health variables, including mortality rates, fire incidents, and urgent care requirements, based on climate indicators and their fluctuations.

An interactive Tableau dashboard provides real-time decision support, enabling participants to make data-driven decisions. Decision-makers engage with the dashboard through TypeForm, allowing decision-makers to observe the direct impact of their choices. A multi-criteria analysis approach is used to evaluate decisions, facilitating the identification of optimal strategies for mitigating public health risks and enhancing emergency readiness during climate-related challenges.

In conclusion, this work offers an innovative, evidence-based approach to addressing public health challenges posed by climate crises. It highlights the significance of taking informed preventive steps to protect public health during climate-related emergencies. Furthermore, it sets a precedent for future research, both in Portugal and globally, with applications extending beyond heatwaves or climate extremes. These insights and methodologies will prove invaluable for policymakers as they navigate climate-induced health crises and strive to build resilience in the face of emerging challenges.

Keywords: Climate-Health Resilience, Data-Driven Health, Predictive Modeling, Data Visualization, Decision Support Systems

Resumo

Com a intensificação das crises climáticas, a necessidade de preparação eficaz em saúde pública torna-se vital. Esta dissertação de mestrado apresenta uma abordagem abrangente para enfrentar esse desafio, ao desenvolver e implementar um sistema de apoio à decisão baseado em evidência. Com foco nas ondas de calor como cenário específico, esta pesquisa combina engenharia biomédica, ciência de dados e gestão em saúde pública.

A pesquisa é suportada por uma extensa revisão da literatura e um cenário realista de onda de calor construído para a região de Lisboa e Vale do Tejo. O exercício simula uma onda de calor de sete dias em julho de 2025, com temperaturas máximas superiores a 40ºC, juntamente com diversos fatores alarmantes e seu impacto nas instalações de saúde. Diversos conjuntos de dados de saúde pública de várias fontes portuguesas são agregados e correlacionados, e modelos de aprendizagem automática são treinados para prever variáveis de saúde pública, incluindo taxas de mortalidade, incidentes de incêndio e requisitos de cuidados urgentes, com base em indicadores climáticos e as suas flutuações.

Um painel interativo em Tableau fornece suporte à decisão em tempo real, permitindo que os participantes tomem decisões baseadas em dados. Os decisores interagem com o painel por meio do TypeForm, permitindo que eles observem o impacto direto das suas escolhas. Uma abordagem de análise multicritério é usada para avaliar as decisões, facilitando a identificação de estratégias ótimas para mitigar os riscos à saúde pública e aprimorar a prontidão de emergência durante desafios relacionados ao clima.

Em conclusão, este trabalho oferece uma abordagem inovadora baseada em evidências para preparar a resposta de emergência médica a crises climáticas. Destaca a importância de tomar medidas preventivas informadas para proteger a saúde pública e estabelece um precedente para pesquisas futuras, tanto em Portugal quanto globalmente, com aplicações que se estendem além das ondas de calor ou extremos climáticos. Essas informações e metodologias serão úteis para os formuladores de políticas à medida que procuram construir resiliência do sistema de saúde perante desafios emergentes.

Palavras-chave: Resiliência Clima-Saúde, Saúde Baseada em Dados, Modelagem Preditiva, Visualização de Dados, Sistemas de Apoio à Decisão

Contents

List of Figures

List of Tables

Abbreviations

ANEPC	Portuguese Emergency and Civil Protection Authority *(pp. 18, 30, 35)*
APA	Portuguese Environmental Agency *(pp. 18, 20, 30)*
CML	Lisbon City Council *(pp. 30, 35)*
DGS	Portuguese General Directorate of Health *(pp. 1, 15, 18, 20, 24, 26, 30, 35)*
DM	Decision-making *(pp. 1, 2, 6, 7, 9–11, 13, 16–19, 21, 24, 25, 27, 28, 30, 31, 34–37, 39, 40)*
DSS	Decision Support System *(pp. 2, 3, 9, 11, 16, 25, 39)*
INEM	Portuguese Medical Emergency Institute *(pp. 18, 25, 30)*
INFARMED	Portuguese Authority of Medicines and Health Products *(p. 18)*
IPMA	Portuguese Sea and Atmosphere Institute *(pp. 15, 18, 20, 30, 35)*
ISN	Portuguese Institute for Lifesaving *(p. 15)*
ISS	Portuguese Social Security Institute *(p. 15)*
LVT	Lisbon and Tagus Valley Region *(pp. 16, 18, 20–22, 26, 30, 31)*
MAE	Mean Absolute Error *(pp. 13, 14, 26, 33, 34)*
MCDA	Multi-Criteria Decision Analysis *(pp. 3, 17, 27, 28, 35, 36)*
ML	Machine Learning *(pp. 2, 3, 12–14, 16, 20–22, 25, 26, 36–40)*
MSE	Mean Squared Error *(pp. 13, 14, 26, 33, 34)*
OSINT	Open-Source Intelligence *(pp. 17, 19, 20, 30, 31)*
PH	Public Health *(pp. 1–5, 7–20, 23–26, 29–31, 36, 37, 39, 40)*
$\mathbf{R^2}$	Coefficient of Determination *(pp. 13, 26)*
RMSE	Root Mean Squared Error *(pp. 13, 14, 26, 33, 34)*
SPMS	Portuguese Shared Services of the Ministry of Health *(p. 20)*
SR	Situation Room *(pp. 2, 7, 8, 16, 18, 34, 35, 39)*
WHO	World Health Organization *(pp. 7, 12, 30)*

1

Introduction

1.1 Context and Significance

Over the last decades and particularly years, silent structural alterations with a significant impact on society have occurred. [2] The COVID-19 pandemic, the war in Ukraine and the attack on Israel, the earthquakes in Syria, Turkey and Morrocco, the wildfires in Canada and the several floods throughout the globe make it evident that the health response to unexpected events must be quick, organised, properly prepared, conscious and sustainable. [3, 4] To prepare teams and leaders for new and unforeseen challenges in Public Health (PH), it is vital to explore different approaches, methodologies and intervention plans while preparing professionals for interdisciplinary and uncertain environments. Moreover, information systems should be implemented to access data to better plan, organise and communicate in such a crisis. [5–7] The preparation for crisis often occurs in small, specialised groups, but in reality, many agents, including the general public and local or institutional leaders outside the planning group, impact the response. [8]

According to the European project Population Health Information Research Infrastructure, NOVA University of Lisbon and Portuguese General Directorate of Health (DGS), Climate Disruptions are one of the three most relevant driving forces in the next decade that could affect the PH system organisation. To prepare for the climatic crisis and extreme weather events, it is important to have a rational organisational response that takes into account possible inherent conditions, diseases, and contaminations. Decision makers should understand the effects of their decisions and work towards increasing preparedness and awareness in the Decision-making (DM) systems. [9]

Due to the need for improvement, digitalisation, and globalisation of PH systems, these have reached a level of complexity in which preparedness plays an increasingly important role. [7] Crises often impact several classes of these systems, enhancing the significance of leading entities, such as the DGS, that ensure the availability of healthcare services to the main and vulnerable population. [5]

As an organisation, reacting to a crisis involves preparedness to activate response mechanisms, planning of resources, and effective communication channels for all actors involved in the resolution. There should be thought-through preparation, well-established leadership, and resilient systems that permit these reactions to be effective. While this should be a relatively simple task given the current information in various fields, societal pressure generates imprudent procedures that hinder the positive outcome of the established systems. [3, 6, 10]

Portugal is a country that faces numerous climate-related challenges, especially the frequent and severe heatwaves and wildfires. In crises, medical equipment is often unavailable due to a lack of or inadequate planning. These events pose a significant threat to PH, particularly to vulnerable groups such as the elderly, children, and those with underlying medical conditions, or low-income groups lacking access to necessary preventive and treatment measures. [11, 12] Climate change is a critical issue in PH because extreme climate phenomena can disrupt public systems and negatively affect the well-being of populations. It has both short-term and long-term impacts on physical and mental health, making it crucial to prepare for and address these impacts with well-designed solutions. [9, 13]

1.2 Concept

In order to effectively handle crisis situations, it is crucial to establish coordination among various agencies with different backgrounds. Frequently, teams may be unfamiliar with each other's capabilities and responsibilities and may find themselves collaborating for the first time during an emergency. The Situation Room (SR) serves as a platform for presenting crisis scenarios, providing all involved parties with a comprehensive view of the situation. This training not only equips leaders with necessary tools and well-defined roles but also enables them to make informed decisions and execute coordinated operations with ease and efficiency. [8]

DM systems assess various indicators' development, thereby identifying each proposed option's impact. The system evolves by analysing the team's ability to solve the problem through decision algorithms and data analytics until decision-makers become more resilient, more sensitive to natural occurrences, and ready to make informed, realistic and accurate decisions.

1.3 Research Goals

This dissertation aims to develop a system that can prepare PH, hospitals, and biomedical planning decision-makers in Portugal to respond effectively to climate change scenarios. The approach involves developing a SR exercise where decision-makers are presented with a heatwave scenario, analyse the information, communicate with other actors, make informed decisions, and are evaluated based on the impact of their choices. The ultimate goal is to improve Portugal's timely and adequate response to climate change.

To address the challenges arising from PH and hospital preparedness and climate change, the incorporation of Machine Learning (ML) is proposed to generate climate-health data that accurately reflects real-world scenarios. Additionally, an interactive Information and Decision Support System (DSS) enhances evidence-based DM and strengthens the robustness of existing systems. The primary objective is to contribute to the advancement of the application of Information and DSSs in addressing the multidisciplinary challenges of PH preparedness in the context of climate change.

Consequently, the following research questions were identified:

How can a realistic exercise for heatwave preparedness be constructed to simulate a climate change crisis scenario effectively?

What are the effective ways to compile and correlate diverse Portuguese PH data sources into a reliable information system for emergency response preparedness?

Can ML models accurately predict health variables using climate indicators?

How is it possible to use Multi-Criteria Decision Analysis (MCDA) to evaluate decisions in a scenario involving climate change and PH?

1.4 Dissertation Organization

This document consists of six chapters, including this introductory section. Chapter 2 provides the literature context of this work and involves a literature review that describes various approaches used in PH preparedness and the benefits of combining different techniques. It also puts the topic into context and retrieves which techniques are most suitable to use, considering the dissertation's objectives. Chapter 3 describes the methodological approach, its implementation, and its considerations. Chapter 4 presents the resulting system developed and inference, while Chapter 5 exhibits the discussion, highlighting the study's positives/advances and limitations. Finally, Chapter 6 summarises the main conclusions of the work and highlights proposals for future work.

The research work described in this dissertation was carried out in accordance with the norms established in the ethics code of Universidade Nova de Lisboa. The work described and the material presented in this dissertation, with the exceptions clearly indicated, constitute original work carried out by the author.

2

State of the Art

2.1 Climate Change Impact on Health

Human life is affected by climate, particularly health. Extreme temperatures cause hyper or hypothermia; sudden weather events cause injuries, migration and hunger; climate conditions alter hazard and circulation of vector, water, food and airborne diseases; and indirect consequences vary from mental health to society and ecosystem disruption. [14]

Promising signs of climate change stabilisation or mitigation are present in Portugal, with reports of a significant reduction in greenhouse gas emissions, the upsurge of efficient trash management and renewable energy usage and adaptations in agriculture, livestock farming and fishing. [15, 16] Despite the positive prospect within Portugal, extreme weather events like drought, heatwaves, wildfires, storms and floods are expected and increasingly common, and their effects add up to the ones caused by "chronic"symptoms such as exposure to pollution or ionising solar radiation. [17, 18]

Climate change has a higher impact on vulnerable public groups, such as the elderly and chronic patients. Climatic agents like heat provoke different reactions, including increased older population death and drastic effects in economies of low-income countries. [12, 19] Research in methods for PH preparedness remains imperative so the gap between opportunities in catastrophic events lessens. [14]

2.2 Public Health Preparedness

Emergencies and disasters can cause significant damage to both health and non-health sectors. These events create stress in the PH sector and highlight the need for readiness and preparation. The healthcare response is built on a foundation of infrastructure, material, and human resources, all essential to a swift and effective response. [20]

In 2010, McCabe proposed a comprehensive framework to improve preparedness based on the separation of ability, willingness, and readiness as three preparation domains. The ability to respond is limited by the practical capability and proficiency of individuals, organisations, or communities in performing necessary tasks during an incident. Willingness considers the psychological disposition toward specific responses. Readiness represents the availability of human and material resources for action. [21]

To create a compelling and comprehensive emergency response system, both inherent and acquired competencies must be developed through training and education. The inherent competencies include knowledge, skills, and abilities necessary to respond to emergencies. The acquired competencies include beliefs, understanding, and confidence in one's abilities, contributing to the willingness to act in emergencies. Plans and policies should be implemented to provide a solid foundation for the emergency response system, ensuring a coordinated and efficient response to any crisis.

A coordinated and comprehensive emergency response system is essential for any crisis. This system should be built on a foundation of infrastructure, material, and human resources, all of which must be readily available to respond to emergencies. In addition, the system must be supported by training and education programs that develop inherent and acquired competencies. [22]

2.3 Complex Interventions in Complex Environments

Organisations face an environment characterised by volatility, uncertainty, complexity, and ambiguity (VUCA). Volatility suggests a rapid change of pace, requiring quick adaptations to these changes. Uncertainty poses a significant obstacle in predicting the outcomes of these changes, making it difficult to prepare for them. Complexity arises from the intricate problems that occur from the overlap of societal and system components, and ambiguity expresses the existing unclear boundaries, which can lead to unsupported decisions and actions. In summary, organisations must be able to navigate these complex and dynamic environments to remain competitive and successful. [23]

When evaluating an intervention, it is crucial to assess its complexity by considering various factors. These factors include the number of components involved, the breadth of behaviours addressed, and the required levels of expertise and skill for both providers and recipients. Furthermore, the complexity of the intervention can be influenced by the number of groups, settings, or levels targeted, as well as the degree of flexibility allowed for both the intervention and its components. [24]

In healthcare, especially in PH, interventions tend to be complex due to the many interacting components involved. [25] It is worth noting that the level of complexity of an intervention is directly related to how it interacts with the context in which it is implemented. As a result, it is essential to consider the mechanisms of change and contextual factors that may impact the intervention's effectiveness in the real world. [26] In the case of a PH intervention, the contextual factors that come into play are diverse, ranging from economic to social, environmental, regional, and many others, which adds to the complexity of the situation and makes it unique from other fields.

With health being an extremely complex context, there is a reluctance to simplify, but action is needed so that the availability to deal with the unknown increases. Even when analysing a complex intervention, researchers can break it down into simpler parts to gain a more manageable perspective. [27] In this case, there is no need to label interventions as complex or simple since the researcher's perspective determines the level of complexity applied. [28]

2.4 Crisis Management

Emergencies are unexpected events that require immediate action but can be handled within available resources and management capabilities. An emergency operations plan should be implemented in such situations, allocating responsibilities, leadership, resources, and stages of action. Disasters, however, are sudden events that can be natural, technological or societal. These events are characterised by significant devastation due to extreme occurrences with huge amounts of energy. Models for emergencies or disasters have different phases, including mitigation and preparedness before the event and response and recovery during and after the event. It is important to consider prevention measures that reduce the impact on vulnerable parties and plans/systems to increase response efficiency before incidents occur. Once the incident has occurred, reducing loss and future strains should be the priority. [5]

Crises demand swift action, decisive DM, and seamless coordination among leaders, public agencies, and policymakers. Given the high stakes, pooling resources and working collaboratively is critical to finding a resolution. [29] However, this kind of cooperation can be challenging due to conflicts of interest, individual concerns, and a lack of structure. [10] Preparing for potential emergencies demands cooperation and collaboration between public well-being agencies, which differing perspectives can complicate. Emergency health and security services are typically accustomed to a fast-paced, command structure-based DM and action-taking environment. In contrast, medical departments usually function in a slower-paced environment that allows for meetings and consensus-building. [8] Given that healthcare leaders turn to government officials for guidance regarding any situation's possibilities and limitations, a well-established organisation and clear assignment of tasks are essential. [30]

Managing a crisis involves two essential parts: responding to the problem and programming the response. Programming the response means planning how resources, e.g., human resources, medical equipment, and response vehicles, will be used at different stages of the crisis, who will supervise the tasks, and how they will be coordinated and controlled. It involves all the organisations in charge of these processes to reduce the event's impact. [3, 14] Crisis preparedness should be an all-hazard approach involving all government organisations to make it applicable to a more extensive range of situations. [5] The methodology presented in Figure 2.1 represents how interdisciplinarity is essential when preparing for a disaster. Evaluations provide changes that should be implemented in reality, and there must be a constant flow of information so that systems are ready to respond in the event of the scenario occurring.

In 2011, Salmon *et al.* organised a training exercise consisting of high-level representatives from various departments, including police, firefighting, paramedic, environment, and electrical. The exercise presented different scenarios, and the representatives discussed their capabilities and necessities. The study concluded that it is crucial to identify roles and responsibilities and promote the constant sharing of information and advances

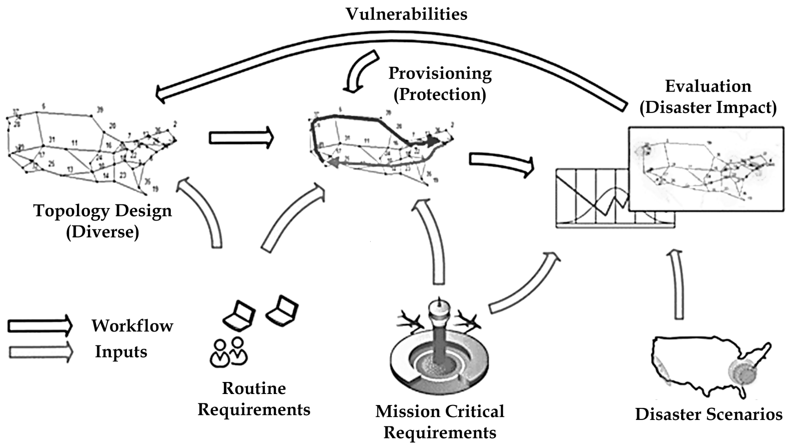

Figure 2.1: Multidisciplinary disaster planning workflow, as proposed by Gardner *et al.* reflects the complexity and various areas involved in the approach. [31]

between different agencies. Ambiguity in leadership can lead to role confusion and ineffective utilisation of resources. [29] This and other studies suggest that recurrent emergency training with the complete system can improve coordination. [29, 32, 33] Establishing transparent relationships in the response system enables actors to exercise their roles better and adapt to new environments. [34]

In 2016, the US Department of Health and Human Services launched PH 3.0, a model designed to increase collaboration amongst different sectors and with society and available data since those are also determinants of health. [30] Data systems should provide accurate data at the right time, filtered to apply to the area and community, thus becoming successful health systems with smart data based on big data. [35] Sell *et al.* compared emergency plans to business activities where the action is interconnected with the final goal of managing the disaster. With this mentality, crisis plans were described as workflows that advance as accomplishments happen. [36]

2.5 Situation Room

During important events and crises, PH and Public Systems have responded in real-time by bringing high-level authorities and experts together in a SR. This allows them to assess different needs and approaches and develop solutions quickly and efficiently. The SR can be used for direct, real-time events or as a preparation medium for potential future events. Responsible crisis managers and organisers must continuously prepare to make the necessary judgments. [3, 8, 37] The World Health Organization (WHO) has emphasised the importance of preparedness among crisis managers and organisations in all sectors of the healthcare system. [38] They must be prepared to make timely and accurate decisions and take necessary actions to respond to the crisis. [39]

SRs can serve as highly advantageous centres during natural and unnatural disasters by having vital information and communication systems that simulate strategic DM centres. Decision-makers can exchange opinions and information by monitoring and analysing previously selected indicators. This helps provide fast and informed solutions for allocating resources (human and material), minimising damage, and coordinating action upon unfolding occurrences. [3] A SR is designed to improve PH preparedness by facilitating interdisciplinary collaboration and streamlining health system efficiency, reducing the time between receiving critical information, making informed decisions, and taking immediate action. [40]

Collaborative settings that require solving complex problems can significantly benefit from having multiple displays available to showcase relevant details and real-time updates. [41] Therefore, it is pertinent to have a variety of information sources and recipients present in a SR exercise, as it enhances communication and fosters a more comprehensive understanding of the situation. This approach allows all the actors involved to contribute and receive information, leading to a more effective problem-solving process because they become receptive to various technical information sources, which motivates them to be receptive to collaboration and different opinions.

2.6 Scenario Training for Preparedness in Crisis

Alexander Pope's quote, "To err is human", reflects on the fallibility of human nature. While this statement holds for many situations, it is unacceptable in the realm of PH, especially during catastrophic situations. Mistakes can occur in any profession, but in healthcare, a single error can have severe consequences. Therefore, healthcare information systems must be designed to assist medical professionals in making the right decisions, minimising the possibility of errors and ensuring the safety of patients. [42]

It is crucial to have technical skills, especially in high-risk professions like healthcare. However, non-technical skills are equally important and often in short supply. Decision-makers in the healthcare industry should possess various skills such as effective communication, teamwork, leadership, and expertise in conflict and fatigue management. [5, 43] Situation awareness is a crucial non-technical skill requiring an individual to be aware of their surroundings, collect and analyse information from various sources, and then use it to make informed decisions. It involves constantly monitoring, identifying potential risks, and taking appropriate action to prevent or mitigate negative consequences. Effectively practising situation awareness is essential in many fields, including aviation, military, healthcare, and emergency response. [10, 44, 45]

Adequate preparation for potential crises is essential for institutions like PH authorities and hospital managers, and training exercises such as realistic simulations and scenario resolution are critical to achieving this goal.Organizations can create adaptable frameworks by experimenting in controlled conditions that promote learning and growth. [43] As noted in [46], "scenarios become a bridge between the existing understanding and new alternative views or frameworks that can be used to interpret what is happening in the outside world". Simulating real-life scenarios allows organisations to test their crisis management systems and develop effective approach models by analysing the outcomes.

By taking a proactive approach to crisis management, institutions can minimise the impact of potential threats and be better prepared to handle them. Simulations are a cost and time-efficient way to achieve this objective. [6, 8, 47]

Simulation for PH and health services preparedness is a type of crisis simulation. It can serve as a research tool to study DM in leadership, a training tool for actors to become more aware of hazards associated with stress and complexity, a way to assess plans by facilitating communication and evaluation of mutual necessities and resources between leaders, and a design decision support tool that can provide information for DSSs. [48]

Efficient access to pertinent information is paramount in developing a successful DSS. To maximise efficacy and acceptance among healthcare professionals, work groups should evaluate workflows, relevant information, DM actors, and indicators while promoting collaboration between developers and users. [49] Post-exercise reports should include specific measures to enhance progress and corrective actions. [8] Predictive models, despite being recognised as critical, are not yet widely applied in research facilities due to funding and publication limitations. [18]

2.7 Evidence-Based Health Information Systems

As referred to, scenario training is a cost-effective measure in crisis resolution. Another cost-effective measure is healthcare information systems that minimise human intervention mistakes and vulnerability through statistical data and situational alarms. [16, 50] Crisis resolution requires efficient resource utilisation and resilient coordination among actors. To achieve this, a system should suggest potential solutions ahead of time. [3] These methods allow planning so that in the moment of action, the focus is the implementation of the planification, continuous and permanent follow-up and alterations according to reality. Progress and result indicators are fundamental to ensure the correct implementation of solutions according to the scenarios that became a reality. [39]

A health information system is a complex system that involves collecting, processing, and analysing various types of data related to PH. This data comes from different sources, such as hospitals, clinics, laboratories, and health surveys. The system is designed to integrate all this information into a single platform, allowing PH officials and policymakers to access the data and generate strategic information to help make informed decisions. The information generated can include disease surveillance, health trends analyses, and resource allocation. The system also ensures that the data is used effectively and ethically, protecting the privacy and confidentiality of individuals and groups whose data is used. Ultimately, a health information system plays a vital role in improving the quality of PH services, identifying areas of need, and preventing and controlling disease outbreaks. [51]

In the realm of PH and emergency health, evidence-based information systems serve as essential tools for informed DM and policy formulation. These systems leverage the capture, transformation, and management at multiple levels, including raw data, processed data (information), and knowledge. [52] Information systems are crucial in ensuring that evidence, often derived from research literature and systematic reviews, is readily accessible and applicable to specific healthcare contexts. However, it's important to recognise that evidence-based decisions extend beyond peer-reviewed publications and encompass a broader spectrum of information sources, including contextual and locally relevant data. [53] Information systems, particularly those harnessing emerging technologies such as Internet-based interactive health communication tools and expert systems, have the potential to facilitate on-demand access to evidence-based knowledge. This entails the creation of clearinghouses for public domain information, tools, and resources, as well as enhancing content dissemination and real-time updates. These systems empower healthcare professionals and decision-makers with the capacity to draw upon a diverse range of evidence and knowledge for sound PH practices, ultimately contributing to improved healthcare quality and more effective disease prevention and control efforts. [54]

Cross-sectoral emergency preparedness through information systems is expected to enable the reaction to events triggered by extreme climate events. [16] PH resilience refers to the ability of "health actors, institutions, and populations to prepare for and effectively respond to crises". It also involves maintaining core functions when a crisis hits and reorganising if conditions require it, informed by the lessons learned during the crisis. Better indicators such as vulnerability and system resilience are needed to improve the probability of effectively dealing with climatic disasters and the consequences that follow. Organisational training and risk management are crucial at this level to establish and replicate effective procedures through complex drills and real-life occurrences. [55]

2.8 Data Visualization in Health

Dashboards in health communication are significant as they play a big role in visualising various aspects of outbreaks, facilitating analysis, and supporting DM. Dashboards have gained importance due to the globalisation of health concerns and the increasing digitisation of data-driven developments. They are particularly relevant in the context of infectious disease surveillance, especially evident during the COVID-19 pandemic, where they serve experts and the general public seeking real-time information. [56]

In an ever-changing global landscape marked by challenges like globalisation and climate change, dashboards emerge as versatile tools capable of addressing a wide range of health issues. They cater to various user groups, including experts, researchers, and specific communities, offering real-time monitoring and data retrieval from diverse sources. Dashboards align with PH objectives related to crisis control, information management, quality of life improvement, and policy adjustment. Moreover, they improve communication and management processes by effectively reporting and sharing data, often employing maps and diagrams. However, challenges persist in data integration, legal compliance, data accuracy, and handling misinformation, particularly in dashboards using social media data. Design considerations are paramount, with maps and diagrams playing a central role, while other visual elements like graphics and animations are less common. The interplay and interpretation of these visual elements warrant further investigation. [57]

The use of PH data dashboards entails a dual exercise of power, where central authorities decide what data should be included and interpret the meaning of trends across communities. This centralised control aims to guide resource allocation and disease prevention. While dashboards have long been used internally in PH, their recent proliferation in response to the pandemic has made them a common tool for public communication. However, there are nuanced considerations. Dashboard creators, often data experts, may not fully align with the needs of the public audience who lack comparable data skills. Furthermore, abundant data is rapidly integrated into dashboards, but not all information is essential for every user. Instead, providing links to resources that empower individuals to modify behaviours and access healthcare in their communities may be more effective in reducing disease risk. Health dashboards should incorporate text-based narratives to engage audiences with varying levels of numerical literacy. Patient profiles and composite cases can enhance dashboards for different user groups. To ensure accuracy, creativity is required in reporting units beyond geopolitical borders. Clear methodological details can enhance transparency and accountability in emergency communication. [58]

2.9 Indicators

Lapão explored the function of new technologies in DSSs. Given national security threats involve many agencies, and their settlement involves abundant information and coordination, methods to measure the effectiveness of the response must be developed. [49] These methods can be focused on measuring the competency of different actors' abilities in emergency preparedness and the coordination between agencies (communication amongst them, mutual acquaintance, formal affiliations, and resource exchange).

While indicators for these types of systems were not found in literature, characteristics of the overall health system and the DM process that should be followed were. Moore *et al.* suggested guidelines for assessing health system preparedness, useful for developing indicators of the efficiency of the systematic response. The information and response system's competency should include preparedness, communication instruments within the command structure and with the general public, adequate surveillance (technologic, epidemiologic, demographic, etc.), structured display of information to support conscious analyses, established strategies and an educated labour force. Competency of the PH system is only detectable via individuals continuously exhibiting abilities such as understanding the role of their area of expertise in the emergency and preservation of PH services, knowing the structural organisation of response and the group or individual role; being aware of the variety and functioning of communication, and recognising their limits/how creativity can help overcome them. Quantifying coordination can be attained by analysing the level of contact between organisations, the number of official planned responses, the amount of shared resources and the knowledge of mutual procedures.

Finally, the defined incident command structure can be examined through its components – command, planning, operations, logistics and finance/administration – and through computing the uniformity of precise language implemented in different agencies. [5]

Lamberti-Castronuovo developed a framework defining the basic properties a health system must possess to prepare for disasters. This was prompted by WHO 's publication of the Health Emergency and Disaster Risk Management Framework in 2019. Preparing for disasters requires identifying vulnerable societal groups and settings to address the needs of more exposed or defenceless parties. These groups may include patient groups, social security ranks, and hospital facilities. Even during staff shortages and personnel fluctuations, essential health services must continue to be delivered to the general public. Strategies should be developed to ensure equal treatment for vulnerable groups, including financial or legal facilitation or alternative models of care, such as telemedicine or patient literacy. Hospitals and emergency rooms must have adequate capacity to handle surges associated with health crises through location and medical professionals' preparation at regional and national levels. Additionally, financial resources must be analysed to ensure funding for planned responses and possible emergency decisions. Examples of the indicators possible to evaluate disaster plans are Leadership and Governance, namely policy planning; Service Delivery, namely continuity of care, integration of services, community engagement, patient and household preparedness; Health Information, namely vulnerability assessment and incident response plan; Health Workforce, namely multidisciplinary team, surge capacity, training and education and safety protection of workers; Medical Products and Technologies, namely adequate medical/lab equipment and supplies and infrastructure and technology; Financing, namely financial resources. [37]

2.10 Machine Learning applied to Medicine

PH data collection involves passive or active surveillance. Passive surveillance is used during outbreaks and to understand disease burden, while active surveillance contacts healthcare providers for specific data. National health ministries and organisations like WHO collect this robust data. However, challenges exist, such as individual data loss due to aggregation, privacy concerns, and delays. Rapid policy-making, as during COVID-19, requires quick access to accurate data, which can be challenging. [59]

In data analysis and forecasting, modelling involves developing a mathematical or statistical representation of a system, phenomenon, or process. ML is a branch of artificial intelligence that involves training machines on data and allowing them to make predictions or decisions without being explicitly programmed. In modelling, ML algorithms are used to learn patterns and relationships within a dataset and to use this learning to make accurate predictions on new data. The algorithms are trained using historical data and can be improved over time as more data becomes available. [60] Developing predictive models involves employing well-established regression analysis methods typically used for causal modelling, including linear regression, log-binomial regression, logistic regression, Poisson regression, and Cox regression. [61]

ML finds extensive utility in population and PH, operating within four principal domains. Firstly, it identifies and elucidates the multifaceted factors influencing medical outcomes across socio-ecological levels, facilitating comprehensive research. Secondly, it aids in designing interventions that account for individual and multi-level influences, addressing the complex nature of medical determinants. Thirdly, ML plays a pivotal role in outcome prediction, encompassing mortality risk, hospital readmissions, and disease prognoses. However, further research should explore health disparities and extend beyond hospital contexts while considering ethical implications. Lastly, ML supports resource allocation by providing insights for DM, treatment effect estimation, and handling missing data. Incorporating multi-level considerations, particularly geographic factors, is vital to prevent resource allocation disparities and promote equitable healthcare access. Within healthcare and PH, ML 's integration promises precision healthcare, early disease detection, personalised medicine, enhanced PH surveillance, informed policy recommendations, and optimised resource allocation to improve overall population health outcomes as technology advances. [62, 63]

2.10.1 Regression Models Evaluation

Regression models are usually not completely accurate in predicting values. To compare the performance of different models, it is important to quantify the errors between predicted and real values. For this purpose, commonly used metrics are Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) and Coefficient of Determination (R^2). [64, 65] Plevris *et al.* examined the importance of using various metrics in evaluating the performance of regression and ML models to obtain accurate predictions. [64] In the following sections, each metric will be examined, describing how it is obtained and discussing how it can be interpreted.

2.10.2 Coefficient of Determination

When using linear models, the R^2 can be defined in terms of the residual sum of squares (RSS) and the total sum of squares (TSS) as

$$R^2 = 1 - \frac{\text{RSS}}{\text{TSS}} = 1 - \frac{\sum_{i=1}^{N}(\hat{p}_i - p_i)^2}{\sum_{i=1}^{N}(p_i - \bar{p})^2}$$

R^2, in its original formulation, quantifies how much the independent variables determine the dependent variable in terms of the proportion of variance. [66] In other terms, this metric expresses the reason between the variance that the model and the total variance can explain. This means higher values of R^2 translate to more useful linear models. [64]

2.10.3 Mean Squared Error

The MSE is one of the most used metrics in ML performance quantification. [64] This metric computes the average squared difference between real and predicted values. When comparing observations with predicted values, it is necessary to square the differences as some data values will be greater than the prediction, meaning their differences will be positive. In contrast, others will be lower, meaning their differences will be negative. Given that the probability is equal for the prediction is higher than the reality or lower, the differences would add to zero and squaring these differences eliminates this situation. [67] The MSE can be calculated using the following formula

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}(p_i - r_i)^2$$

One setback of using this metric is its proneness to outliers. If a sample has an associated error way larger than most other samples, the square of the error will be even greater. [64]

2.10.4 Root Mean Squared Error

Also, one of the most commonly used metrics, the RMSE, calculates the square root of the average of the squared differences between predicted and real values, which is the same as calculating the square root of the MSE. [68]

$$\text{RMSE} = \sqrt{\text{MSE}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(p_i - r_i)^2}$$

2.10.5 Mean Absolute Error

The MAE is a commonly used metric for evaluating predictions. It is similar to the RMSE in that it measures the difference between predicted and actual values. MAE treats all errors equally and does not penalise larger errors more heavily. Instead, it calculates the average of the absolute error values, ensuring the result is always positive. [69] The MAE can be obtained by this formula

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}|p_1 - \hat{p}_i|^2$$

2.11 Climatic Evolution scenarios in Portugal

Van der Heijden proposed, in 1996, a scenario development methodology that has since been applied in Portugal by Lapão *et al.* in 2000. [49] The first phases were achieved in meetings of various specialists and leaders who established three relevant scenarios: Innovate or Procrastinate, Climatic Disruption and Digital PH. After identifying the three areas of importance in PH preparedness in Portugal, Lapão *et al.* further developed each in time intervals. A chronological representation is presented in 2.2. [15]

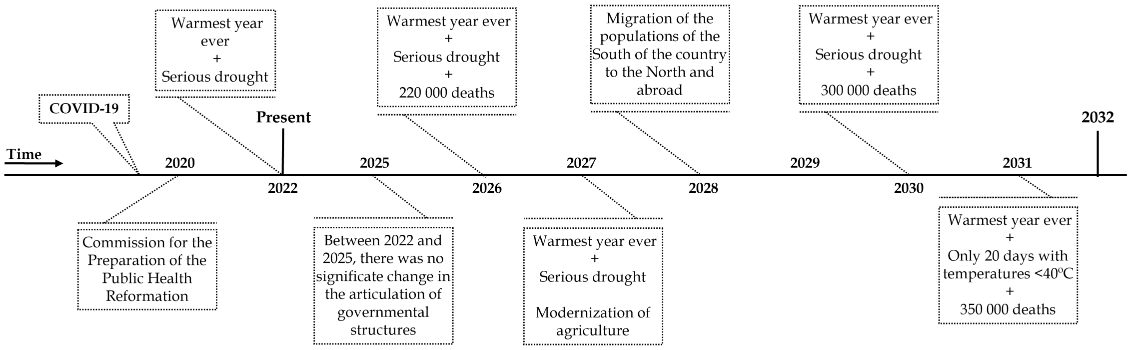

Figure 2.2: Climatic disruption scenarios identified in Portugal by the DGS and Universidade Nova de Lisboa for the next ten years. Adapted from [15].

In the period spanning from 2022 to 2025, the monitoring of seasonal health becomes a collaborative effort involving various PH institutions, including Portuguese Social Security Institute (ISS), Portuguese Institute for Lifesaving (ISN), and Portuguese Sea and Atmosphere Institute (IPMA) and regional medical services. Their joint initiatives aim to identify potential health crises and coordinate multiagency responses promptly. This era also sees the development of legislation to address the challenges posed by sudden extreme temperatures, not only by identifying vulnerable groups but also by proactively implementing solutions.

Transitioning into 2025 to 2028, the PH system is significantly restructuring, driven by governmental and political involvement in medical support. This restructuring extends to a broader spectrum of medical areas, emphasising prevention and education for the general public and healthcare organisations. Technological measures are introduced to monitor the impact of radiation on vulnerable populations. Additionally, practical steps are implemented to safeguard civilians in the face of climatic events, aiming to reduce the necessity of migration to coastal and temperate regions. The restructuring efforts also encompass the redistribution and coordination of medical personnel based on regional events and requirements.

From 2028 to 2032, there is notable recognition and licensing of multidisciplinary medical care teams, which leverage their diverse skills in conjunction with digital advancements to develop global health solutions. Technology finds widespread application, particularly in agriculture, leading to innovative solutions for addressing malnutrition-related challenges in PH. This period marks a continued evolution towards a more integrated and technology-driven approach to healthcare and PH management.

3

Methodology

This chapter proposes a novel methodological approach to assist key stakeholders and decision-makers in the PH field in Portugal. The strategy aimed to improve responsiveness to a prolonged heatwave scenario by implementing a DSS that allowed for the future implementation of various climate or contextual schemes.

3.1 General Overview of the Methodological Approach

Figure 3.1 summarises the technical approach developed in this work.

Figure 3.1: Methodological Framework implemented.

Initially, the focus was on designing the scenario to serve as the basis for the SR. This scenario would determine many subsequent steps, as the data and indicators were intrinsically connected to the storyline. Once a heatwave scenario was settled on, it was time to choose the actions that PH and emergency agents needed to take. These actions were based on health action plans and policies.

To identify the relevant environmental and health indicators that could be affected by the scenario and the ones typically used in DM, it was necessary to decide on the scenario and decision points. Once this was done, data was collected from open-source platforms and direct contacts with entities.

The various data sources resulted in different organisations, granularities, and parameters within the indicators. Therefore, a thorough organisation and aggregation of the data was performed so it could be further analysed and applied. This task resulted in data frames associated with different granularities, all related to the Lisbon and Tagus Valley Region (LVT) region or Portugal. These data frames were further analysed to observe environmental and health data associations.

A heuristic solution in ML was developed to generate realistic data to support the scenario. This solution provided a predictive algorithm with the capacity to create reasonable data that allowed DM to be guided.

A dashboard and decision hub were developed to present the scenario and the data produced in the SR. The dashboard showed the information system so decision-makers could visualise the evolution of the populational indicators. The decision hub could be accessed from each participant's mobile phone or computer.

Finally, to evaluate the participants' performance, a MCDA is performed so that the decisions can be checked according to the relevant components of emergency response and their relative importance.

3.2 Scenario Design

Scenario analysis and contingency planning were fundamental components of this research, as they formed the basis for understanding DM and provided a well-defined and plausible context for the exercise. This section outlines the procedures and considerations involved in analysing contingency plans and creating a realistic heatwave scenario.

3.2.1 Evaluation of Heat-Health Contingency Plans

The initial task was to assess the effectiveness of the heat-health contingency plans developed by PH authorities in Portugal. These plans ensure PH readiness and offer a well-defined framework for dealing with heatwaves. Passive Open-Source Intelligence (OSINT) research was conducted to gather publicly available documents important to the study, analysing that information critically and with a clear objective. The phases of this research were preparation, collection, processing, analysis and production. [70]

In the preparation phase, the requirements were established. Documents had to include terms such as climate change, PH, clinical equipment, health providers, contingency plans, summer, heat, air quality and related keywords. This comprehensive list of keywords was chosen to ensure the retrieval of documents encompassing the broader context of PH preparedness during heatwaves. It allowed for a more nuanced understanding of the subject by encompassing relevant facets, including climate change considerations in the health response and specific heat-related challenges.

The protocols and reports were meticulously sourced throughout the collection phase from Portuguese and internationally recognised PH agencies and governmental bodies with a proven track record of implementation within the Portuguese context. This selection criteria aimed to encompass a broad spectrum of expertise and approaches to heatwave preparedness, drawing from the global pool of knowledge and best practices. By considering internationally recognised protocols and strategies, the research ensured a comprehensive assessment of PH preparedness in Portugal. It complemented the highest standards for addressing heatwaves on a global scale.

The evaluation of the documents was based on several topics, such as adaptation to climate change, healthcare response, resource allocation, community vulnerability, and communication strategies. Adaptation to climate change referred to how plans incorporated climate projections and considerations to ensure adaptability. Healthcare response showed how the increase in demand affects emergency and capacity coordination.

Resource allocation included allocating medical supplies, medication, personnel, and spaces. Community vulnerability considered the needs of vulnerable groups such as the elderly, children, and individuals with pre-existing health conditions. Communication strategies referred to the dissemination of information and advisories.

To organise data collection, the collected data was further separated based on the Portuguese authorities responsible for the area of management, such as IPMA, DGS, Portuguese Emergency and Civil Protection Authority (ANEPC), Portuguese Environmental Agency (APA), Portuguese Medical Emergency Institute (INEM), Portuguese Authority of Medicines and Health Products (INFARMED), and others. These stakeholders were also identified as the most relevant decision-makers for the SR exercise. In the exercise, ideally, one or more representatives of each entity should partake.

3.2.2 Extreme Heatwave Scenario Development

The second step in this methodology was the creation of a comprehensive heatwave scenario that would take place in the LVT Region. This scenario was designed to closely mimic a real-world extreme heatwave event, providing a meticulously structured backdrop for subsequent DM and in-depth data analysis. This scenario connected the previously decided heatwave narrative exacerbated by climate change with the action plans collected, all while focusing on the challenges identified in the extensive review of the literature.

The creation of this detailed heatwave scenario served as a foundational element, shaping the subsequent phases of the research. It acted as a dynamic framework within which DM processes could be rigorously examined, and the effectiveness of the evidence-based information system could be reviewed for health preparedness in climate crises.

The methodological approach presented in Handbook on Simulation Exercises in EU PH Settings was followed for creating the scenario. [71] It ideally described a PH emergency or event and served as the basis for the development of a PH emergency exercise. When creating the scenario, participants' background information, immediate consequences of the event, location variations, and the event's date and time were considered and decided. The scenario required a narrative delineated before the scenario's design and divided to create the sequence of events in the storyline. The storyline would then be divided into incidents presented as injects that provided the information and problems to solve, limiting participants' behaviour and placing pressure on them to take action and make decisions. Given that it was a discussion-based simulation, the final exercise exhibited more specific and realistic incidents and questions for reflection on emergency response procedures.

To create a realistic and comprehensive evaluation framework, a heatwave timeline was developed, reflecting potential scenarios that PH authorities in Portugal might face during a heatwave event exacerbated by climate change. The timeline was carefully designed, considering various factors, such as historical heatwave and climatic data, geographical characteristics, populational density, and urban infrastructure.

Data was then discussed in group meetings in the Digital & Smart HealthCare Laboratory, where the international, multicultural and multi-age group agreed upon a climate evolution timeline. The defined scope, duration and severity of the climate scenario propelled by the heatwave alert were later validated by PH and climate science experts. Being innovative research related to fields out of the scope of the study, the collaboration with relevant stakeholders, including PH authorities and meteorologists, was essential to ensure the scenario's authenticity and relevance. Their input provided valuable insights into the likely challenges and responses during a heatwave.

3.2.2.1 Scenario Structure

During the Analysis and Production phase of the OSINT, after the heatwave timeline validation, it was time to correlate it to the DM framework. To achieve this, the timeline was divided into sections, each prompted by an inject representing external climatic events. Additionally, occasional alerts indicated critical developments, and finally, the object of the evaluation was the decisions related to these events. This structure aimed to simulate the complexity of real-time DM by associating each component with a date and time.

For each decision node within the framework, options were created based on action plans related to the topic. The possibilities for response included at least one option that could deceive the participants. Since this exercise mainly dealt with emergency response, the approach adopted was to include a correct option that could be implemented effectively in a short response time and have a positive effect on the health system, in addition to incorrect options that, although relevant and necessary in the systematic context, could not be completed promptly to resolve the issue proposed. The critical decision points comprised resource allocation, communication strategies, and health interventions.

Amidst the framework, there were several junctures where decisions had to be made. However, only a select few of them had a considerable influence on the trajectory of the scenario. The framework was strategically limited to keep a check on the number of probable outcomes. The critical decisions that had the power to alter the scenario's narrative were carefully interwoven within the framework. This created an engaging and dynamic environment for participants to navigate through while permitting to perform the evaluation effectively.

3.3 Health and Climate Data

3.3.1 Selection and Collection of Data

Once the timeline and framework were established, health and climate-related data were collected to inform and support the DM process via an information system. The data selection was centred on providing clear decision criteria for the decision-makers to make timely and effective choices with generally available data that they would be accustomed to analysing.

Active OSINT research was conducted to gather the necessary data. In this purview, aggregated databases were explored, gathering relevant variables for the study. These variables primarily included historical weather data, demographic information, and data about the healthcare infrastructure. The Portuguese entities responsible for these data sources were contacted via email to obtain the required data. The emails sent to these entities either aimed to request historical data that was not publicly available or to explain the intended use of data and understand whether there could be more relevant information.

The contacted entities encompassed IPMA, DGS, APA, and Portuguese Shared Services of the Ministry of Health (SPMS) to obtain time series data spanning a minimum of 10 years (2012-2022). This data comprised climate, air quality, mortality, morbidity, and various health indicators. Furthermore, cross-sectional records of population statistics and resources were extracted from PORDATA, the certified statistics repository of Portugal, using data available up to 2022. Efforts were made to obtain and utilise data that pertained specifically to the LVT region. In that way, more precise and valuable conclusions could be drawn according to the characteristics and dynamics of this area.

3.3.1.1 Machine Leaning Considerations

An essential consideration in this process was ensuring adequate data for ML models. It was known that ML models typically required at least ten times the number of samples as features. [72] Given the complexity of the data, which consisted of a range of climate variables, air pollutant concentrations, mortality rates, morbidity records, and health indicators, having ten years of records was essential.

A decade's worth of data provided at least ten samples for each day for each feature, offering the ML model a substantial dataset to learn underlying patterns effectively. A large dataset was critical for training the models to predict health outcomes in various scenarios.

Moreover, the 10-year timespan enabled the ML models to predict climate and health outcomes across different seasons, economic conditions, and PH crises. This increased the models' robustness and adaptability, making them suitable for various applications.

3.3.2 Data Aggregation

Following the successful data collection, the next step involved data aggregation and preprocessing, executed through a custom Python script. The script was designed to take input time-series data files with timestamps and perform various operations such as handling date columns, splitting columns, filtering data, and resampling data based on user-defined parameters. This script facilitated the data preparation for subsequent ML and data analysis tasks.

Because the data collected originated from multiple entities and came in different formats, developing a tailored approach to harmonise and prepare the data for subsequent analysis was imperative. Combining effective data selection, data collection, and subsequent data preprocessing formed the foundational steps for building ML models to support DM and statistically analyse the relationships between parameters.

3.3.2.1 Data Granularities

One of the significant challenges faced during data aggregation was dealing with data that spanned different granularities. These datasets exhibited a spectrum of temporal resolutions, ranging from high-frequency hourly data to lower-frequency monthly, and even yearly data. The script was designed to categorise and manage data based on their temporal granularity, creating distinct data files aligned with a specific time scale. The following temporal granularities were encountered and meticulously handled:

- Hourly Data: Hourly cadence information was available in some datasets, mainly in weather and air quality records. The script used an averaging mechanism to consolidate hourly values into daily summaries. This reduced data dimensionality and ensured compatibility with lower temporal resolutions.
- Daily Data: Most datasets had a daily level of granularity. These records were used without modification, providing a balanced representation of variables over time according to the daily structure and evolution of situational timelines.
- Weekly, Monthly, Quarterly and Yearly Data: The script effectively incorporated the records into the data frame file with the respective interval for lower granularity.

3.3.2.2 Geographical Standardization

Since all the databases employed had a national scope, new disparities in data granularity emerged, spanning from individual municipalities and districts to Regional Health Administrations and encompassing the entire country. The goal was to accurately represent the geographic region of LVT. Therefore, measures were implemented to attain data uniformity and uncover meaningful associations.

The goal eas to include data from all constituent municipalities, the LVT regional health authority and administrative districts. When feasible, records were aggregated by merging individual datasets about these specific subregions. In this case, the amalgamation process was executed for each timestamp registered in the final data frame. This process involved aggregating cumulative data by summation, preserving the cumulative nature of variables. Conversely, data characterised as percentages or standalone numerical values underwent averaging to maintain data integrity and consistency.

However, due to data availability constraints, an alternative approach had to be employed when complete data unification was unattainable. In such cases, the script was configured to incorporate data representing the entirety of Portugal. This inclusion strategy ensured that no temporal gaps existed in the aggregated dataset. It also guaranteed the veracity of the data, as estimating or predicting without a plausible motive would result in incorrect data and hinder the proccess.

This approach ensured that irrespective of the source or granularity of data, the resultant dataset provided a cohesive representation of the LVT region, ready for subsequent analyses within the specified temporal context.

3.3.2.3 Technical Implementation

The data preprocessing phase is a crucial step in data analysis and modeling. To address the intricate challenges encountered during data preprocessing, a custom Python script was implemented. This pivotal stage involved converting raw and disparate data into a structured and harmonized dataset, which is well-suited for in-depth analyses.

To achieve this, several powerful libraries in Python were used, serving a distinct yet interconnected role in data transformation, including data manipulation, numerical computations, date management, and data visualisation. The harmonious integration of these libraries ensured the dataset's integrity, consistency, and appropriateness.

- Pandas was the workhorse for data manipulation. It allowed for the efficient loading and handling of data, transforming it into highly structured and versatile data frames. Within Pandas, various methods and functions were employed to clean, filter, and transform data, ensuring that it met the specific requirements of the analysis. This included removing duplicate entries, handling missing values, and reformatting columns to standardise data types.

- NumPy provided essential support for mathematical and numerical operations. It was used extensively for data aggregation tasks, such as calculating summary statistics, including mean, median, and standard deviation. NumPy's array data structure facilitated the efficient storage and retrieval of numerical data, making it an integral part of the aggregation process.

- The Datetime library was crucial for handling date and time-related data. It enabled the script to accurately parse timestamps, extract date components (e.g., day, month, year), and perform calculations with time intervals. This was especially important when aggregating data over specific periods, such as daily or monthly averages.

- While Matplotlib is primarily known for data visualisation, it played a role in the preprocessing phase. The library generated various plots and graphs to visualise data distributions, trends, and outliers. These visual representations were invaluable for exploratory data analysis, helping identify patterns and anomalies in the dataset.

In summary, the custom Python script meticulously leveraged these libraries, to perform the data preprocessing pipeline. Pandas and NumPy handled data manipulation and numerical operations, Datetime managed time-related calculations, and Matplotlib facilitated data visualisation. The seamless integration of these libraries ensured that the raw, heterogeneous data was transformed into a structured and harmonised dataset, setting the stage for subsequent ML analyses and insights.

3.4 Climate-Health Correlations

The analysis of climate-health correlations represented an important but slighter component of this research endeavour. This critical investigation sought to uncover and elucidate the intricate relationships between climatic parameters, air quality, and various health indicators. A comprehensive examination of these associations was undertaken to understand better how climatic conditions might influence PH outcomes, particularly in heatwaves and their potential worsening due to climate change. While correlations were observed, they do not equal causation, as even when two variables are correlated, it does not signify that one caused the other. Still, valuable insights into potential relationships between different variables could be retrieved.

The first consideration in this analysis was the distributional characteristics of the climate and air quality data. The time-series characteristics of the data were put aside as the goal was to understand the impact of the environment and not the evolution throughout the seasons/months. The Kolmogorov-Smirnov test was employed to assess the normality of these datasets rigorously. This statistical test scrutinised whether data adhered to a normal Gaussian distribution, a fundamental assumption underlying many traditional statistical methods. In the present study, it became evident that the climate and air quality data did not conform to this normality criterion, as indicated by the remarkably low p-values obtained during the testing process. These p-values, less than 0.001, signified that the likelihood of observing such non-normally distributed data under the assumption of normality was exceedingly improbable.

The ramifications of this non-normally distributed data were twofold. Firstly, it necessitated the employment of alternative statistical techniques that did not rely on the normal distribution assumption. Secondly, it underscored the complex and multifaceted nature of climate and air quality parameters that exhibited non-linear and irregular behaviours. Consequently, the Spearman correlation emerged as the most suitable statistical method.

The Spearman correlation, a non-parametric counterpart to the Pearson correlation, offered several advantages in the context of non-normally distributed data. Rather than relying on linear relationships, the Spearman correlation focused on the presence and strength of monotonic associations, making it resilient to the irregularities observed in climate and air quality data. By utilising rank-based comparisons, the Spearman correlation provided a robust framework for exploring relationships.

Spearman's correlation coefficients fell from -1 to 1, and their values conveyed distinct meanings. A Spearman correlation coefficient of 1 signified a perfect positive monotonic relationship, meaning that when one variable increased, the other consistently increased systematically, i.e. with a consistent and predictable pattern of change. Conversely, a correlation coefficient of -1 indicated a perfect negative monotonic relationship, wherein as one variable increased, the other consistently decreased systematically. These perfect correlations, whether positive or negative, implied a strong and consistent association between the variables. In contrast, a correlation coefficient of 0 denoted the absence of a monotonic relationship between the variables. It suggested that there was no discernible trend or systematic pattern in how the variables changed concerning each other.

To comprehensively investigate these relationships, a systematic and data-driven approach was adopted. As referred, the objective was to uncover meaningful associations that transcended statistical significance, focusing on elucidating the strength and directionality of these connections. The initial step involved developing a new Python script meticulously designed to calculate the p-values and correlation coefficients for every pairwise combination of variables within the monthly, weekly and daily data frames.

The utilisation of p-values served as a statistical filter in this analysis. These values provided a null value if there was no significant correlation between the variables under examination, which was the goal. The threshold for significance was set at a p-value less than 0.01, making it a criterion to decide if a correlation was potentially meaningful.

Following the computation of p-values, the next step involved the classification of correlations based on their strength. This classification system provided a structured framework for discerning the magnitude of associations between variables. Correlations were categorised into four distinct groups: weak (0.3-0.5), moderate (0.5-0.7), strong (0.7-0.9), and very strong (>0.9). This categorisation not only aided in simplifying the interpretation of results but also facilitated the identification of correlations that bore substantial implications for PH research and policy. The stratification was based on the understanding that not all correlations, even if statistically significant, have equal practical significance. By classifying correlations based on their strength, the analysis was able to distinguish between relationships that required further investigation and those that, while statistically significant, may have limited practical relevance in real-world scenarios.

In essence, this rigorous methodology ensured that the correlations examined in the subsequent analysis were statistically robust and possessed meaningful magnitudes of association. It allowed for prioritising correlations that exhibited more significant potential to inform PH DM and interventions, particularly in mitigating the adverse health effects of climate-induced challenges.

3.5 Selection of Data for the Decision Support System

Several factors were considered when selecting the appropriate health indicators for the exercise. Firstly, the responsiveness measures recorded by DGS and reported in the weekly seasonal response reports indicated that specific indicators were already deemed relevant by the organisation. [73] The variables referred to in those reports were:

- SNS24 and INEM surge
- Emergency calls for burnings, solar exposure, and nausea/vomits
- Consultations in Primary Healthcare
- Rate of respiratory infections, vomit, diarrhoea/gastroenteritis or dehydration
- General mortality rate and specific for COVID-19
- Positive flu and COVID-19 cases
- Bed occupation

However, not all variables were present in the daily or weekly granularity datasets and attempting to infer these missing variables from the monthly data, whether through ML or statistical methods, would not yield accurate results. This would happen primarily because monthly data represented a coarser resolution than daily data, resulting in a substantial loss of information during the aggregation process. [74] As a result, temporal disaggregation methods would likely hield low accuracy for the resultant high-frequency series, i.e. the daily series. [75]

Considering these limitations and the availability of various daily coarse data sources, a strategic decision was made. The data with a daily record was chosen as the foundation for developing the DSS, as it guaranteed the system's outputs would possess the accuracy and reliability necessary for informed DM. In parallel, the coarser granularity datasets, which lacked daily records, were retained strictly for correlation studies.

A notable advantage emerged in the data selection process regarding climatic variables: all climate-related data but one possessed a daily granularity. This fortunate consistency in temporal resolution simplified the procedure as it allowed for straightforward data integration and processing. With daily granularity being the standard across practically all climate datasets, all records could confidently be included in both the DSS 's development and the subsequent correlation studies.

This uniform granularity provided several key advantages. First, it ensured that the climate data used in the DSS aligned with the daily health indicators, facilitating a more accurate understanding of how climate variables impacted PH outcomes on a day-to-day basis. Second, by incorporating the entirety of climate data into the correlation studies, relationships and dependencies between climatic conditions and health metrics were uncovered at a granular level. This comprehensive approach provided valuable insights into the complex interplay between climate and PH. Thirdly, there was no need for temporal disaggregation or complex alignment procedures, which streamlined the data preparation phase. This efficiency was particularly advantageous in ensuring the timely availability of accurate information for decision-makers.

3.6 Predictive Model for Health Outcomes

In the context of this work, the utilisation of ML played a pivotal role in generating the data required for subsequent incorporation into the interactive dashboard, a fundamental component of the research. ML algorithms were designed to extract meaningful information from an amalgamation of diverse PH and climate-related datasets sourced from multiple Portuguese repositories to create the dataset tailored for the dashboard. These datasets encompassed a broad spectrum of variables, ranging from health indicators to climate parameters, all captured at daily granularity.

3.6.1 Model Selection

Given the goal was to predict parameters and not perform a classification, four regression models were chosen and compared to find the one that better fitted the data. These models were Linear Regression, Random Forest Classifier, K-Neighbors Classifier, and Decision Tree Regressor. Two steps governed the selection of the most appropriate model:

1. A relevant set of evaluation metrics was selected to evaluate the effectiveness of the prediction models. The chosen metrics were the R^2, MSE, RMSE, and MAE. These provided insights into the models' ability to explain variance in the target variable and the accuracy of their predictions.

2. The models were then applied to the dataset, and the metrics were calculated. The results provided numerical measures of how well each model captured the patterns in the data and accurately predicted the target variable.

3.6.2 Model Characteristics

The study used various climate and air quality parameters as input, listed in Appendix A, Table A.1. Temporal data such as the day, month, and year were considered to capture any possible time-dependent patterns. These parameters were established quantitatively based on the scenario's narrative to reflect the environment's evolution in the scenario.

In response to these inputs, the model provided a set of health-related outcomes, spanning a broad spectrum of categories, presented in Appendix A, Table A.2 and Table A.3. These outcomes encompassed mortality statistics, categorised by location (e.g., unknown, healthcare institution, domicile), cause (e.g., natural, external, under investigation), and age group (e.g., < 1 year, 1-4 years, 5-14 years, etc.). Furthermore, the model generates data related to emergency medical services, including the activation of helicopters, ambulances, and other medical response units. Additionally, it provided information on various healthcare parameters, such as urgent care attendance, waiting times, and infection rates. While some were the aggregated national data, these numbers were reported by DGS as being the ones used in their health impact analysis.

The primary purpose of the predictive model was to create accurate data based on the patterns and connections between climate, air quality factors, and health outcomes. By learning from past data, the model could understand complex relationships and predict health-related events and indicators based on environmental data. Given the model was trained with LVT area records, it generated data for this area.

3.7 Emergency Response Decision Support System

The retrieved dataset provided a comprehensive overview of how the current climatic situation affected different health indicators. As referred to in Section 3.2.2.1, only a limited number of decision nodes within the scenario had the potential to bring about significant changes in the narrative. In the event of a wrong decision being made at these three critical nodes, the impacted indicators experienced an increase of 30%, which would put participants under more pressure and highlight mistakes made.

The interactive dashboard, constructed using Tableau, played a central role in presenting the dynamic narrative of the scenario. It drew its data from the dataset created by the predictive model that replicated the climate situation in 2025. Then, four controllers of the dashboard were designed. The first controlled the day of the scenario and the climate parameters shown to enable the evolution of the exercise with enhanced realism, as participants would have real-time access to pertinent data. The other three filters were linked to the mentioned critical decision nodes within the scenario that allowed participants to explore different decision pathways and witness the consequences of their choices.

The other pivotal component of the preparedness exercise was the DM, which was facilitated through the use of Typeform. This platform served as the interface for participants to engage with the DM process. The implementation was relatively simple, as it is a straightforward platform. The injects and decisions were entered, and the presentation was adjusted for computer and mobile phone displays. To differentiate participants, only the represented entity was asked. Typeform facilitated DM and served as the repository for recording and storing participants' responses. It could capture the nuanced DM process, showcasing the various perspectives and choices made by participants. This provided the possibility of a comprehensive overview of the journey, decisions, and potential consequences.

3.8 Multi-Criteria Analysis

The evaluation of DM within the preparedness exercise was carried out using MCDA. To ensure a structured and comprehensive approach to MCDA, a detailed guideline provided by Infrastructure Australia was meticulously followed. This guideline was the foundation for implementation and ensured that the evaluation process adhered to established best practices and standards.[76] Using MCDA, a robust DM methodology, enabled the systematic evaluation of the participants' choices. Based on multiple criteria or factors, it provided a framework for assessing and comparing these options to determine their relative merits and drawbacks. Additionally, it was valuable since it was a scenario where decisions significantly impacted various aspects of the complex surrounding environment.

The DM evaluation process involved identifying relevant criteria and assigning weights to these criteria, reflecting their relative importance in the DM context. Subsequently, each alternative within the exercise was assessed against these criteria, leading to an objective evaluation. The outcome of this process offered valuable insights into the effectiveness and implications of different decision pathways within the scenario.

By adhering to the guidelines provided by Infrastructure Australia, the MCDA process was executed systematically and transparently, ensuring rigour and validity during evaluation. This methodology contributed to the overall robustness of the DM assessment, allowing for a comprehensive analysis of choices made during the preparedness exercise.

3.8.1 Criteria Identification

The first crucial step in applying the MCDA was to identify and weight relevant criteria, with the sum of weights being 1. This determined the specific criteria that would be used to assess and compare various decision options within the preparedness exercise. The careful selection and weighting of these criteria were fundamental as they served as the basis for evaluating the effectiveness and implications of decisions made during the exercise. The criteria identification and weighting phase was characterised by a comprehensive examination of the factors most pertinent to the decision context. This ensured that all critical aspects were considered and appropriately weighted in the evaluation process. It also encompassed the consideration of indicators and criteria found in the literature review and resulted in the criteria and weights shown in Table 3.1.

Table 3.1: Identified criteria and attributed weights for the Multi-Criteria Decision Analysis.

Criterion	**Attributed weight**
Health Impact	0.2
Infrastructure Resilience and Adaptation	0.2
Interagency Coordination	0.2
Emergency Response	0.1
Socioeconomic Impact	0.1
Public Awareness and Education	0.05
Long-Term Sustainability	0.05
Community Vulnerability	0.05
Psychosocial Impact	0.05

Several considerations guided the selection and weighting of these criteria. Firstly, "Health Impact", "Infrastructure Resilience and Adaptation", and "Interagency Coordination" were accorded the highest weights, each assigned a weight of 0.2. This decision was rooted in the primary goal of the preparedness exercise, which was to enhance healthcare resilience during climatic crises. These criteria were intrinsically linked to the core objectives of safeguarding health infrastructure, promoting adaptability, and fostering effective coordination among relevant agencies. Therefore, they carried significant weight in the assessment process.

Subsequently, "Emergency Response"and "Socioeconomic Impact" were assigned weights of 0.1, reflecting their secondary but critical roles. Emergency response was considered a fundamental aspect of crisis management, and its weight ensured that it remained a central consideration in all decision options. Furthermore, socioeconomic impact was considered vital as it had shown direct implications for PH outcomes, warranting its inclusion and a notable weight in the evaluation framework.

Lastly, the criteria "Public Awareness and Education", "Long-Term Sustainability", "Community Vulnerability", and "Psychosocial Impact" were assigned weights of 0.05 each. These criteria encompassed various indicators that would collectively contribute to understanding the population's response to implemented measures. While their weights were lower, they were selected for their capacity to provide valuable insights into the broader societal and psychological implications of the decisions made during the exercise.

In sum, the selection and weighting of these criteria were driven by their alignment with the exercise's overarching goal of delivering health and emergency response during crises. The resulting framework ensured a systematic evaluation of decision options, considering both immediate health impacts and broader societal considerations.

3.8.2 Scoring

The subsequent phase entailed scoring the various alternative answers for each decision concerning each criterion, followed by the normalisation of said scores. A standardised scale from 0 to 1 was adopted to streamline this process. This scale simplified the subsequent analysis by ensuring that all scores fell within a consistent range for each criterion.

In the scenario designed, almost all decisions encompassed three alternatives and more often than not, one of the options failed to satisfy a given criterion completely. Each choice was evaluated based on its ability to meet the requirements to determine the best option. A score of 1 was given to the alternative that strongly fulfilled the criterion, while a score of 0 was given to the option that did not. However, if an alternative partially fulfilled the criterion but was not the primary focus, it was given a score of 0.5, indicating a moderate level of completion. This evaluation method allowed for a comprehensive analysis of each alternative and helped make informed decisions.

Once the alternatives had been scored and normalised, the next step involved calculating the weighted scores for each option. This was achieved by multiplying the normalised scores for each criterion by their respective weights. The resulting values were then summed up for each alternative, yielding a singular numerical representation of each option's performance across all criteria. This final aggregated score allowed for a straightforward ranking of the alternatives. The alternative with the highest score would be deemed the most favourable choice, aligning with the exercise's objective of identifying the optimal decision based on a comprehensive evaluation of all relevant criteria.

4

Results

4.1 Scenario

As a result of the passive OSINT research, the comprehensive set of documents obtained outlined a clear and detailed plan of action where all procedures were combined. These documents provided an actionable roadmap that was followed to achieve the scenario.

- Seasonal Health Contingency Plans from DGS, Regional Health Administrations, hospitals, and Local Health Units [77–79]
- National Plan for the Prevention and Control of Vector-Borne Diseases from DGS [80]
- Water Contingency Plans from city councils and APA [81, 82]
- National and Municipal Emergency Plans from ANEPC [83, 84]
- Health Plan for World Youth Journeys from the Portuguese Ministry of Health [85]
- Vector Surveillance Reports from the National Vector Surveillance Network [86]
- Guide for Health-Based Actions During Heatwaves from the Pan American Health Organization [87]
- WHO Heat Health Action Plans [88]

After analyzing the retrieved documents, several guidelines were considered to create an exercise storyline that allowed the central authorities to participate in the simulation while being tested on being informed and prepared with the best practice procedures. Although many groups could benefit from the exercise, in the case of the heatwave and its impact on the PH system in Lisbon, the ideal participants would be a group of representatives from DGS, ANEPC, IPMA, Lisbon City Council (CML), and INEM, as these are the primary DM entities in such situations.

4.1.1 Heatwave Storyline

On July 1st, 2025, a heatwave of severe proportions was detected to be striking the LVT Region in three days. The IPMA team quickly detected the event, and a train of actions followed to mitigate the effects of the heatwave. However, the heatwave lasted longer than expected, and other factors contributed to the worsening situation.

On July 5th, due to a prolonged absence of precipitation, drought surfaced in three municipalities of LVT, posing significant risks to the population. Lack of water affected crops, livestock, and general well-being. The PH response was also at risk as infrastructures and personnel faced limited water supply and increased medical care demand.

On the 10th, the air quality severely deteriorated due to strong winds and air particles from the African desert. The air was filled with pollutants and particles, severely threatening the population's health. People with respiratory problems, children, and the elderly were the most affected, and hospitals were overburdened with patients.

After the heatwave slowed down, on July 16th, unexpected extreme weather struck the region. Severe rain, thunder, floods, and fires occurred almost simultaneously in different parts of the city, forcing resource management and flexibility when the infrastructures were already bursting at the seams. The floods damaged buildings and infrastructures, and the fires added to the already polluted air.

The scenario was designed to encourage effective and interdisciplinary collaboration in DM. It consisted of 33 decision points and four injects that supplied the most important and current information about the situation. Each inject had 6-8 decisions, and each decision had 2-4 alternatives, resulting in a total of 103 options and one open-answer decision. You can find the entire scenario with all options and explanations in Appendix B, and a simplified diagram of the storyline is presented in Figure B.1

To narrow down options and make the DM process more manageable, three key decisions were identified as impactful. These decisions were 1.2.2, 2.2, and 3.3. In decision 1.2.2, participants were asked to choose how to control fire risk and emergency response. In decision 2.2, participants were tasked with deciding how to coordinate the implementation of hydric preservation measures during drought. In decision 3.3, participants had to decide whether to close schools or not when air quality deteriorated, affecting children and the elderly.

4.2 Climate and Health Data

The active OSINT research combined data from several sources. The references provided data from health, climate or demographical data and are presented in Table 4.1. The process of data aggregation involved retrieving four distinct data frames that contained all the relevant data. These data frames were created by combining daily, weekly, monthly, and quarterly data and saved in the .csv format. These data frames were then used as the foundation for all the data processing and analysis. These comprehensive data frames allowed for a detailed examination of the data and helped ensure accurate results.

4.2.1 Correlations

Spearman's correlation analysis evaluated the associations between health and environmental parameters in the daily, weekly and monthly datasets. Note that the weekly dataset

Table 4.1: Indicators and data sources included in the study.

Source	Platform	Indicators	Granularity
DGS	SICO [89]	Mortality	Time-series: Daily
SPMS	SNS Transparência [90]	Health	Time-series: Daily, Weekly, Monthly, Quarterly and Annual
APA	QualAr [91]	Air Quality	Time-series: Hourly, Daily
IPMA	(Direct Collaboration)	Climate	Time-series: Daily, Monthly
PORDATA	PORDATA [92]	Demographical	Fixed values

had only one variable initially and to further comprehend the associations, the daily variables were aggregated in this temporal granularity. In this result section, given the large datasets, only the moderate, strong and very strong correlations found are presented. All the results are shown in Appendix C.

The UV index parameter showed negative moderate correlations with various health parameters (Table C.1). The total number of deaths was negatively and moderately correlated with the UV index simultaneously in the daily and weekly datasets, with a slightly higher association in the weekly granularity. Regarding deaths per age group and UV index, the daily dataset showed correlation in only one group, 75-84 years, while the weekly dataset showed correlations in several age groups, including 55-64, 65-74, 75-84 and >85 years old. In the monthly dataset, strong and very strong positive correlations were found between the UV index and health variables (Table C.2). Some of these were not found in previous studies, such as the strong association between UV index and aggression and diving occurrences.

Negative moderate correlations were additionally reported between temperatures and health variables (Table C.3). Deaths at home and in health institutions showed correlations with mean temperature in the daily dataset and deaths in the population aged >75 years old. The daily mean temperature also presented a negative association with urgent care respiratory infection rate and flu appointments. As reported in the literature, mean temperatures showed a strong positive correlation with the number of allergy occurrences. Similar to what was found regarding the UV index, aggression occurrences correlated strongly and positively with the mean temperatures in the monthly datasets (Table C.4).

In Table C.5, moderate correlations in the daily dataset related to the concentration of air pollutants are presented. Ozone correlated negatively with Influenza incidence, while nitrogen dioxide and benzene correlated positively. In the weekly dataset, the sulfur dioxide concentration negatively correlated with the primary health care appointments, particularly non-scheduled appointments, while benzene and carbon monoxide are associated positively with home and health institution deaths, respectively. In daily records, benzene positively and moderately correlates with emergency ambulance calls, priority one emergency occurrences, and urgent care respiratory infection rate. Table C.6 exhibits the strong correlations between health indicators and air pollutants. The sulfur dioxide's negative correlation with psychiatric problems and suicide occurrences and the strong positive correlation with diabetes occurrences should be highlighted. Additionally, nitrogen dioxide and nitric oxides positively correlate with pediatric emergencies.

4.3 Predictive Model for Health Outcomes

4.3.1 Model Selection

The outcomes of the model evaluation process, as presented in Table 4.2, illuminate the model selection procedure's findings.

Table 4.2: Performance of the Machine Learning models tested for the predictive model.

Model	R-squared Score	Mean Squared Error	Root Mean Squared Error	Mean Absolute Error
Linear Regression	0.1883	365.1	19.10	8.846
Random Forest Classifier	0.0294	299.6	17.3095	8.266
K-Neighbors Classifier	-0.6432	917.1	30.28	13.73
Decision Tree Regressor	-0.3646	326.9	18.08	8.537

- The Linear Regression model exhibited the highest R-squared score, signifying its capability to explain a substantial proportion of the variance in the target variable. Additionally, it demonstrated superior predictive accuracy as evidenced by the lowest MSE, RMSE, and MAE. The combination of these metrics shows an aptitude for delivering precise predictions and robust performance.
- While the Random Forest Classifier demonstrated a better R-squared score than some other models, it still lagged significantly behind Linear Regression. Its relatively higher MSE, RMSE, and MAE values underscored the model's diminished predictive accuracy when compared to the selected Linear Regression model.
- The K-Neighbors Classifier displayed a negative R-squared score, implying a performance that fell short of a simple horizontal line. This model's high MSE, RMSE, and MAE values further accentuate its inadequate predictive capabilities.
- The Decision Tree Regressor also yielded a negative R-squared score, reflecting subpar model performance. Although it outperformed the KNeighborsClassifier in terms of MSE, RMSE, and MAE, it still trailed behind Linear Regression, indicating inferior predictive accuracy.

In light of these evaluation metrics and the primary objective of the predictive task, the Linear Regression model was unequivocally designated as the optimal choice among the four models. Its superior R-squared score, coupled with the lowest MSE, RMSE, and MAE values, underscored its superior predictive performance and its ability to elucidate variance in the target variable, making it the preferred model for the specific task.

4.3.2 Predictive Model

The predictive model developed for this study was designed to establish a relationship between climate and air quality data and the corresponding health outcomes. With the selected input, the model provided the output for the scenario. The result was a heuristic solution to the problem that sufficiently supported the SR with data that created realistic and relevant DM.

4.4 Situation Room

Figure 4.1: Final overview of the Tableau Dashboard considering best decision-making procedures.

Two distinct methods were implemented to facilitate seamless communication within the SR. The first method is the health information system, a comprehensive dashboard providing real-time updates on critical health indicators. The second method is an interactive platform that serves as the DM hub within the SR.

Figure 4.1 presents the best final overviews of the dashboard, considering in the three impactful decisions, the correct alternatives were selected. On the other hand, Figure D.1 shows the worst final overview, assuming the three impactful decisions were inappropriate. In Figures D.2 and D.3 are presented the entry page of the DM platform, featuring a QR code for faster access and an example decision point.

The dashboard offers an interactive interface to track environmental parameters over time. Users can adjust the date range using the slide bar to view daily changes and trends. The filter system provides a more comprehensive view of the data concerning the decision points where participants evolve and influence the graph's displayed information. As the exercise advances beyond the three impactful decisions, three additional filters become available to provide deeper insights into the effect of decisions on health parameters.

The DM platform is designed to help users answer questions by presenting them with available options. Each user needs to carefully consider the options and select the best answer that suits the given situation. However, ensuring a consensus is reached on critical decisions is equally important. This collective approach is crucial to ensure effective and efficient progress of the scenario. It should be noted that the platform only allows the selection of one option out of the three available decisions due to its technical background.

4.4.1 Multi-Criteria Decision Analysis

To assess the effectiveness of the exercise, a thorough evaluation was necessary. The methodology provided used the MCDA presented in Appendix E to conduct this evaluation. It involved considering nine specific criteria for each decision point. The participants can achieve 24.45 points or less, thus ensuring a comprehensive and accurate performance assessment according to the result.

The combination of the two interfaces with the MCDA resulted in a SR where stakeholders can collaborate and make informed decisions based on the available data. Additionally, the multi-criteria factor of the evaluation allows to make post-exercise analysis on the areas lacking attention or the areas where that attention is.

4.4.2 Trial exercise

Due to time constraints, it was not possible to conduct an official SR with official entity representatives within the time frame of this study.

Nevertheless, a trial exercise was conducted with a group of researchers with vast knowledge of the health, health policies and health-applied engineering areas that acted as representatives from IPMA, DGS, ANEPC and CML. This test run resulted in invaluable insights that were seamlessly incorporated into the final work presented in this dissertation.

The group received an overall score of 77%, indicating their performance in the emergency response scenario. However, their score was the lowest in the Long-Term Sustainability criterion with 59%, which indicates that they did not balance all the considerations regarding the duration of the scenario. On the other hand, their highest scores were in the Interagency Coordination and Community Vulnerability criteria with 77% and 74% respectively. This shows that the group had a heightened concern for the last two aspects of emergency response, but didn't consider the persistence of the decisions.

5

Discussion

Public and emergency health are complex systems that require highly multidisciplinary and informed DM processes. The DM process should include doctors, epidemiologists, PH practitioners, and other relevant experts. The latest research and information should inform this process to ensure the most effective decisions are made.

In situations of increased societal pressure, such as environmental crises, it becomes challenging to maintain focus and structure. The DM process becomes more complex due to the heightened level of uncertainty and the need to respond quickly to the crisis. In Portugal, contingency plans are used to establish ways to improve response pathways continuously. These plans are essential to ensure that the response to PH emergencies is efficient and effective. However, contingency plans alone have been proven insufficient in some cases, and more extensive preparation and resilience are required. Information, preparedness, and resilience should be at the base of the process to ensure fewer faulty decisions occur. To achieve this, decision-makers must be adequately trained, equipped with the necessary tools, and have access to the latest information and research.

The lack of preparation for the climate change crisis is because these are new situations to which no one has been exposed. As a result, stakeholders take more time than ideal, and there is a hurdle of it being their first exposure to the situation. This lack of experience and preparation increases the likelihood of making faulty decisions.

The proposed methodology combined different methods with both a technical and a social component. By considering data from the literature, ML methods were combined with a MCDA approach to predict the outcome of an established climate scenario. This should help prepare decision-makers in the health sphere. With this system, decision-makers can make more informed decisions, and the response to PH emergencies can be more efficient and effective. Although some limitations were recognised, several advantages resulting from the use of this proposed methodology were identified.

5.1 Positive Points of the Methodological Approach

The methodological approach of this study crossed over key areas when modelling scenarios and making related decisions. This approach assessed the impact of various solutions in the DM process, ultimately leading to a comprehensive system that simulates the significant patterns. The simulation tool employed had not been previously developed nor considered in any form by the PH professionals, but its potential for analysing the impact of hypothetical organisational changes in decision pathways has left them enthusiastic.

PH is an intricate system that requires an interdisciplinary approach, combining expertise from climate science, air quality monitoring, and PH. This approach provides an unbiased and technological perspective, ultimately enhancing the understanding of complex relationships between environmental factors and health outcomes. This approach is grounded in evidence-based practices, ensuring that all findings are based on rigorous scientific methods, thus increasing the credibility of the results.

The system is supported by a vast set of data from different sectors, including a comprehensive time-series data frame spanning over a decade. This data integration allows for predicting health outcomes, providing a comprehensive analysis of the potential impact of environmental factors on PH in Portugal. A granular analysis of health data by considering various factors, including age groups, mortality causes, and geographic locations, creates a level of detail that allows for tailored interventions and policies.

In the correlation analysis conducted, several moderate and strong correlations were found. Quality of air has been reported to influence health. [93] The analysed datasets confirmed that UV index, temperature and several air pollutants could affect health status and death registries. The association between mean temperatures and death had been established in Portugal, with protocols already in place for both extremely high and low temperatures that reinforce professionals in healthcare centres and hospitals and increase communication about health posing risks for the general population and specific concern groups. An information not found in previous studies and deemed relevant was an association between temperature increase and aggression. It may be interesting to follow up, as it could justify additional law enforcement for greater alertness during heat periods.

Additionally, ozone, nitrogen dioxide, and benzene concentrations showed moderate associations with the number of flu appointments and benzene levels correlated with ambulance activation, immediate life-risk emergencies, and respiratory infection emergencies. The monitorisation of air pollutants could help prepare hospitals to adapt responses. With accurate predictions of increases in the components, healthcare providers would be better able to prepare for the repercussions. The same reflection applies to nitrogen dioxide and nitric oxide since both are strongly associated with pediatric emergencies.

Many studies have highlighted the importance of ML, statistical analysis, and simulation exercises regarding the preparedness and resilience of the health sector. Nevertheless, no other literature combined technical approaches in different areas to create a novel approach to the preparedness problem. Developing a predictive model is a strength of this approach, as it provides a tool for forecasting health outcomes based on climate and air quality variables. This tool can be valuable for PH preparedness and DM.

Health Information Systems provides real-time decision support for PH authorities, empowering informed decisions, especially during climate-related health crises. It also showcases the digital and technical opportunities that can be explored to allow for more information use and flow within the healthcare sector.

The trial results provided strong evidence that the tool developed is a valuable guide for health DM. It evaluates preparedness while providing a comprehensive analysis of areas that are being addressed effectively and those that need attention, showing decision-makers their strengths and weaknesses in order to make informed decisions.

The process was methodologically organized with the aim of achieving flexibility and customization. The system developed should be easily adaptable to various climate events, including heatwaves and cold waves. Additionally, the system can be applied efficiently in different contexts, ensuring compliance. This dissertation presents a transparent methodology that outlines the steps taken to process the data, develop the predictive model, and analyze the results. This transparency enhances the research's reproducibility.

5.2 Limitations and Improvement Points

Using extensive data from multiple sources can result in inaccuracies and missing information, especially in public and aggregated data that goes through various systems, policies, and processes. These concerns were acknowledged by the stakeholders involved in using and providing the data repositories. The accuracy and reliability of the predictive model are heavily dependent on the quality of input data. Though these limitations justify lower accuracy, they still offer reliability in the results. To address limitations, data validation and cleaning techniques can be employed to rectify missing or inaccurate data points.

One crucial concern was ensuring temporal lags between environmental exposures and health outcomes were captured throughout the development process. This time frame would significantly impact which environmental factors affected health when these impacts occurred and what interventions could be made at the appropriate time. Two improvements can be made to address this issue. The first is quantitative and focuses on the data already captured. The second is qualitative and focuses on data yet to be captured. The system could analyse temporal patterns and lags in the data to provide more accurate predictions of health outcomes. Alternatively, a retrospective analysis of past measures could be conducted to comprehend their effects and assess any delays in observed impacts through established bridges with the authorities.

The ML model is a preliminary approach that has shown minimal signs of concern so far. However, it could benefit from a more in-depth analysis of its accuracy and interpretability. The literature on climate predictions is extensive, and the literature on health predictions is growing, which makes this problem solvable. Additionally, the predictive model considered only environmental data from one day to predict the health data on that same day; another improvement could be to alter the model so that it encompassed not the separate daily data but also a certain number of neighbouring days, therefore resulting in a better understanding of the environmental and medical context.

Moreover, the system currently only considers climate and air quality factors. However, other external factors, such as socioeconomic status, healthcare access, and population mobility, could affect health outcomes. Although some aspects are difficult to incorporate, others are relatively simple and could yield better results.

6

Conclusions

Concisely, the development and implementation of the evidence-based DSS for PH Climate Crisis Preparedness represents a significant advancement in capacity to address the escalating challenges posed by climate-induced conditions, namely heatwaves. This innovative system demonstrated its potential to increase PH preparedness by providing timely, data-driven, and evidence-based insights into the complex dynamics between climate conditions and PH outcomes.

The Heatwave SR represents an immersive and high-pressure environment where decision-makers grapple with the escalating consequences of their choices. As real-time climate and health data continuously flow into the system, the stakes intensify with each passing moment. The immersive nature of the SR keeps participants acutely aware of the dire implications of wrong decisions. When sub-optimal choices are made, the system's dynamic dashboard vividly portrays the worsening health indicators, creating a palpable sense of urgency. This immersive pressure cooker drives decision-makers to think critically, collaborate effectively, and act swiftly in the face of mounting challenges, ultimately amplifying the system's efficacy in PH preparedness and response. One of the key strengths of this system lies in its ability to seamlessly integrate climate and air quality data with health indicators, allowing for a holistic understanding of the impacts of heatwaves. By employing ML techniques in a creative way, the system has enhanced health data's accuracy and predictive power, empowering decision-makers with valuable information to allocate resources and plan targeted interventions preemptively.

However, as with any pioneering endeavour, some areas warrant further attention and refinement. The reliance on non-parametric statistics due to the non-normal distribution of climate and air quality data necessitates ongoing exploration to optimise the modelling process. Expanding the system's scope to encompass a broader array of multi-level factors, including sociological and contextual elements, will enable a more comprehensive statistical description of health outcomes.

The collaborative engagement of key stakeholders, including PH authorities and meteorologists, has been instrumental in ensuring the authenticity and practicality of the system. Sustaining and strengthening these partnerships is imperative to continually enhance the system's performance and alignment with real-world DM processes. Furthermore, these are the objects of the exercise, meaning that it is in all interest to receive more feedback and continuously deliver new, better and more automated solutions.

In summary, the Evidence-Based Decision Support System for Health Climate Crisis

Preparedness: A Heatwave Situation Room stands as an inventive tool in advancing the ability to mitigate the health impacts of climate-induced heatwaves. By addressing its inherent limitations and fostering collaborative efforts, this system holds the potential to significantly bolster evidence-based DM and fortify the PH defences against the growing threats of climate change.

Given the forward-looking nature of the work, several potential future developments are possible. First, there is potential to transform the system into a live information hub by establishing direct connections to climate, health, and other relevant data sources. This would enable real-time updates and an even more immediate response to emerging threats.

Furthermore, the data processing and aggregation phase can be fully automated, reducing manual intervention and streamlining the system's efficiency. Advanced ML algorithms could be employed to improve the accuracy and speed of data transformation continually. This would benefit the exercise and all PH entities as it would provide a means for a data flow between systems.

In addition, future research could delve into an in-depth statistical analysis of the extensive dataset already collected. This analysis would provide valuable insights into the impact of climate change on Portugal and its various regions, aiding in the development of targeted strategies for climate crisis preparedness.

To expand the system's utility and effectiveness, exercises can be designed to challenge not only the preparedness and resilience of response teams but also their level of information and adaptability. These exercises could encompass a range of scenarios, including climate-related events and broader assessments of the PH system's state. The system can be fine-tuned by training predictive models with diverse datasets to detect and address potential vulnerabilities and critical situations within the PH infrastructure and resources.

Overall, the future work for the system holds the promise of a more responsive, automated, and informed approach to climate crisis preparedness and PH DM, ensuring greater resilience in the face of evolving challenges.

Bibliography

[1] J. M. Lourenço. *The NOVAthesis LaTeX Template User's Manual*. NOVA University Lisbon. 2021. URL: https://github.com/joaomlourenco/novathesis/raw/main/template.pdf (cit. on p. ii).

[2] C. R. Watson, M. Watson, and T. K. Sell. "Public Health Preparedness Funding: Key Programs and Trends From 2001 to 2017". In: *American journal of public health* 107 (S2 2017-09), S165–S167. DOI: 10.2105/AJPH.2017.303963 (cit. on p. 1).

[3] R. Azadehdel, K. Dadashtabar, and E. Enami. "Design and Architecture of A New Crisis Situation Room (CSR)". In: DBLP, 2009, pp. 302–308. DOI: 10.1145/1556176.1556230 (cit. on pp. 1, 6–9).

[4] I. Subbarao et al. "A consensus-based educational framework and competency set for the discipline of disaster medicine and public health preparedness". In: *Disaster Medicine and Public Health Preparedness* 2 (1 2008), pp. 57–68. DOI: 10.1097/DMP.0b013e31816564af (cit. on p. 1).

[5] S. Moore et al. "Public health preparedness: A systems-level approach". In: *Journal of Epidemiology and Community Health* 61 (4 2007), pp. 282–286. DOI: 10.1136/jech.2004.030783 (cit. on pp. 1, 6, 8, 12).

[6] K. Campbell. "Ready to respond: How health-care professionals and public-health officials can work in concert to detect and stop disease outbreaks". In: *Nature* 610 (2022), S38–S40. DOI: 10.30476/ijms.2020.85810.1537 (cit. on pp. 1, 9).

[7] T. R. Zolnikov et al. "Enhancing public health preparedness, response, and recovery capabilities through the Florida Hurricane Response Hub". In: *Climate Risk Management* 30 (2020-01). DOI: 10.1016/j.crm.2020.100251 (cit. on p. 1).

[8] N. Lurie, J. Wasserman, and C. D. Nelson. "Public health preparedness: Evolution or revolution?" In: *Health Affairs* 25 (4 2006), pp. 935–945. DOI: 10.1377/hlthaff.25.4.935 (cit. on pp. 1, 2, 6, 7, 9).

[9] C. Linares et al. "Impacts of climate change on the public health of the Mediterranean Basin population - Current situation, projections, preparedness and adaptation". In: *Environmental Research* 182 (2020-03). DOI: 10.1016/j.envres.2019.109107 (cit. on pp. 1, 2).

[10] R. Westcott et al. "Natural hazards and adaptive response choices in a changing climate: Promoting bushfire preparedness and risk reduction decision-making". In: *Social Sciences Humanities Open* 2 (1 2020), p. 100065. DOI: 10.1016/j.ssaho.2020.100065 (cit. on pp. 1, 6, 8).

[11] K. L. Ebi. "Managing climate change risks is imperative for human health". In: *Nature Reviews Nephrology* 18 (2 2022-02), pp. 74–75. DOI: 10.1038/s41581-021-00523-2 (cit. on p. 2).

[12] T. L. P. Health. "Mitigating climate change must be a priority for public health". In: *The Lancet Public Health* 6 (9 2021-09), e620. DOI: 10.1016/S2468-2667(21)00190-0 (cit. on pp. 2, 4).

[13] J. Hospedales. *Caring for the Earth for better health and well-being of all: addressing climate change as a planetary health emergency*. 2021. URL: https://climate.nasa.gov/vital-signs/global- (cit. on p. 2).

[14] H. Frumkin et al. "Climate change: The public health response". In: *American Journal of Public Health* 98 (3 2008-03), pp. 435–445. DOI: 10.2105/AJPH.2007.119362 (cit. on pp. 4, 6).

[15] L. V. Lapão et al. *Cenários Saúde Pública 2032: Implicações para a organização da Saúde Pública em Portugal Universidade NOVA de Lisboa Direcção-Geral da Saúde*. Direção Geral da Saúde, 2023-01 (cit. on pp. 4, 15).

[16] S. Mayhew, S. van Belle, and M. Hammer. "Are we ready to build health systems that consider the climate?" In: *Journal of Health Services Research and Policy* 19 (2 2014-04), pp. 124–127. DOI: 10.1177/1355819613516943 (cit. on pp. 4, 9, 10).

[17] P. K. Nicholas et al. "A CLIMATE: A Tool for Assessment of Climate-Change–Related Health Consequences in the Emergency Department". In: *Journal of Emergency Nursing* 47 (4 2021-07), 532–542.e1. DOI: 10.1016/j.jen.2020.10.002 (cit. on p. 4).

[18] X. Rodó. "Forecasting disease". In: *Nature* 610 (2022-10), S45 (cit. on pp. 4, 9).

[19] W. H. Organization. *Public Health Advice on Preventing Health Effects of Heat*. World Health Organization, 2011, 34 p. (Cit. on p. 4).

[20] Y. Khan et al. "Public health emergency preparedness: A framework to promote resilience". In: *BMC Public Health* 18 (1 2018-12). ISSN: 14712458. DOI: 10.1186/s12889-018-6250-7 (cit. on p. 4).

[21] O. L. McCabe et al. "Ready, willing, and able: A framework for improving the public health emergency preparedness system". In: *Disaster Medicine and Public Health Preparedness* 4 (2 2010-06), pp. 161–168. ISSN: 19357893. DOI: 10.1001/dmp-v4n2-hcn10003 (cit. on p. 4).

[22] S. J. Lee et al. "Human preparedness: Relational infrastructures and medical countermeasures in Sierra Leone". In: *Global Public Health* 17 (12 2022), pp. 4129–4145. ISSN: 17441706. DOI: 10.1080/17441692.2022.2110917 (cit. on p. 5).

[23] A. Puji et al. "Change Management Model in The Era of Volatility, Uncertainty, Complexity and Ambiguity (VUCA) Using Scenario Planning Analysis". In: *The International Journal of Social Sciences World* 4 (2 2022), pp. 307–316. DOI: 10.5281/zenodo.7485139. URL: https://www.growingscholar.org/journal/index.php/ (cit. on p. 5).

[24] M. Campbell et al. "Education and debate Framework for design and evaluation of complex interventions to improve health". In: (2000). URL: www.mrc.ac.uk/complex_packages.html (cit. on p. 5).

[25] P. Craig et al. *Developing and evaluating complex interventions: The new Medical Research Council guidance*. 2008-10. DOI: 10.1136/bmj.a1655 (cit. on p. 5).

[26] K. Skivington et al. "A new framework for developing and evaluating complex interventions: Update of Medical Research Council guidance". In: *The BMJ* 374 (2021-09). ISSN: 17561833. DOI: 10.1136/bmj.n2061 (cit. on p. 5).

[27] L. V. Lapão. *The Role of Complexity Dynamics in the Innovation Process within the new Primary-Care Governance Model in Portugal*. 2008 (cit. on p. 5).

[28] M. Petticrew. "When are complex interventions 'complex'? When are simple interventions 'simple'?" In: *European Journal of Public Health* 21 (4 2011-08), pp. 397–398. ISSN: 11011262. DOI: 10.1093/eurpub/ckr084 (cit. on p. 5).

[29] P. Salmon et al. "Coordination during multi-agency emergency response: Issues and solutions". In: *Disaster Prevention and Management: An International Journal* 20 (2 2011), pp. 140–158. DOI: 10.1108/09653561111126085 (cit. on pp. 6, 7).

[30] K. Oliver et al. "The Power of Prevention: Prevention and Preparedness in Public Health". In: *American Journal of Preventive Medicine* 62 (4 2022-04), pp. 650–652. DOI: 10.1016/j.amepre.2021.12.004 (cit. on pp. 6, 7).

[31] M. Gardner et al. "Determining Geographic Vulnerabilities Using a Novel Impact Based Resilience Metric". In: *Journal of Network and Systems Management* 24 (2016-07). DOI: 10.1007/s10922-016-9383-y (cit. on p. 7).

[32] C. Paris, E. Salas, and J. Cannon-Bowers. "Teamwork in multi-person systems: A review and analysis". In: *Ergonomics* 43 (2000-09), pp. 1052–75. DOI: 10.1080/00140130050084879 (cit. on p. 7).

[33] R. Chen et al. "Coordination in Emergency Response Management". In: *Commun. ACM* 51 (2008-05), pp. 66–73. DOI: 10.1145/1342327.1342340 (cit. on p. 7).

[34] G. Steil and M. Gibbons-Carr. "Large group scenario planning: Scenario planning with the whole system in the room". In: *The Journal of Applied Behavioral Science* 41 (1 2005-03), pp. 15–29. DOI: 10.1177/0021886304272888 (cit. on p. 7).

[35] K. DeSalvo and Y. C. Wang. "Health informatics in the public health 3.0 Era: Intelligence for the chief health strategists". In: *Journal of Public Health Management and Practice* 22 (2016), S1–S2. DOI: 10.1097/PHH.0000000000000484 (cit. on p. 7).

[36] C. Sell and I. Braun. “Using a Workflow Management System to Manage Emergency Plans”. In: 2009-05. URL: https://www.researchgate.net/publication/228571462 (cit. on p. 7).

[37] A. Lamberti-Castronuovo et al. “Primary health care disaster preparedness: A review of the literature and the proposal of a new framework”. In: *International Journal of Disaster Risk Reduction* 81 (2022-10). DOI: 10.1016/j.ijdrr.2022.103278 (cit. on pp. 7, 12).

[38] W. H. Organization. *Health emergency and disaster risk management framework*. World Health Organization, 2019, xi, 31 p. (Cit. on p. 7).

[39] G. M. Espíndola and M. A. Maeyama. “Resignification of health planning: situational strategic planning combined with the implementation of a health situation room and evidence-informed policy”. In: *Brazilian Journal of Health Review* 5 (6 2022-12), pp. 25180–25198. DOI: 10.34119/bjhrv5n6-258 (cit. on pp. 7, 9).

[40] “The Situation Room as a management tool: the case of the Municipal Health Secretariat of Salvador”. In: *European Journal of Public Health* 30 (5 2020), pp. v551–v552. DOI: 10.1093/eurpub/ckaa166.061. URL: https://academic.oup.com/eurpub/article/30/Supplement_5/ckaa166.061/5913981 (cit. on p. 8).

[41] C. Burghardt et al. “Implementing scenarios in a smart learning environment”. In: 2008, pp. 377–382. DOI: 10.1109/PERCOM.2008.96 (cit. on p. 8).

[42] I. of Medicine (US) Committee on Quality of Health Care in America. *To Err is Human: Building a Safer Health System*. Ed. by L. T. Kohn, J. M. Corrigan, and M. S. Donaldson. Kohn, Linda T. Nacional Academy Press, 2000, p. 287 (cit. on p. 8).

[43] R. M. U. Kaneko and M. H. B. de Moraes Lopes. “Realistic health care simulation scenario: What is relevant for its design?” In: *Revista da Escola de Enfermagem* 53 (2019). DOI: 10.1590/S1980-220X2018015703453 (cit. on p. 8).

[44] E. S. Toner. *Creating Situational Awareness: A Systems Approach workshop on medical surge capacity hosted by the Institute of Medicine Forum on Medical and Public Health Preparedness for Catastrophic Events What Is Situational Awareness?* 2009. URL: https://www.ncbi.nlm.nih.gov/books/NBK32848/ (cit. on p. 8).

[45] J. Giri et al. “The situation room: Control center analytics for enhanced situational awareness”. In: *IEEE Power and Energy Magazine* 10 (5 2012), pp. 24–39. DOI: 10.1109/MPE.2012.2205316 (cit. on p. 8).

[46] K. van der Heijden. “Scenarios: The Art of Strategic Conversation”. In: 2nd ed. John Wiley Sons, Ltd, 2005. ISBN: 0-470-02368-6 (cit. on p. 8).

[47] C. Judek et al. "Crisis simulation scenario building methodology that considers cascading effects". In: *Journal of Integrated Disaster Risk Management* 8 (2 2018-12), pp. 24–43. DOI: 10.5595/idrim.2018.0329. URL: https://www.idrimjournal.com/article/11666-crisis-simulation-scenario-building-methodology-that-considers-cascading-effects (cit. on p. 9).

[48] M. Kleiboer. "Simulation Methodology for Crisis Management Support". In: *Journal of Contingencies and Crisis Management* 5.4 (1997), pp. 198–206. DOI: 10.1111/1468-5973.00057 (cit. on p. 9).

[49] L. V. Lapão. *Preparação para a Resposta a Situações de Crise: A Resiliência Assente na Capacitação com Sistemas Inteligentes de Apoio à Decisão*. 2020-08, pp. 47–77. DOI: 10.47906/ND2020.156.02. URL: https://doi.org/10.47906/ND2020.156.02 (cit. on pp. 9, 11, 14).

[50] A. A. Kuatbayeva. "Fuzzy logic in healthcare situation room modelling". In: vol. 2014-January. Association for Computing Machinery, 2014-10, pp. 540–542. DOI: 10.1145/2691195.2691294 (cit. on p. 9).

[51] P. A. H. Organization. *Health Information Systems*. https://www.paho.org/en/topics/health-information-systems. Accessed on 14/09/2023 (cit. on p. 9).

[52] J. Zvárová. *On the medical informatics structure*. 1997 (cit. on p. 9).

[53] R. J. Rodrigues. *Policy and Practice Information systems: the key to evidence-based health practice*. 2000 (cit. on p. 10).

[54] A. Epizitone, S. P. Moyane, and I. E. Agbehadji. *A Systematic Literature Review of Health Information Systems for Healthcare*. 2023-04. DOI: 10.3390/healthcare11070959 (cit. on p. 10).

[55] K. L. Ebi. "Indicators for monitoring and evaluation adaptation within health systems". In: 2018. DOI: 10.3390/ijerph15091943. URL: https://www.researchgate.net/publication/323915363 (cit. on p. 10).

[56] T. R. Katapally and S. T. Ibrahim. "Digital Health Dashboards for Decision-Making to Enable Rapid Responses During Public Health Crises: Replicable and Scalable Methodology". In: *JMIR Research Protocols* 12 (2023). ISSN: 19290748. DOI: 10.2196/46810 (cit. on p. 10).

[57] A. Schulze et al. *Digital dashboards visualizing public health data: a systematic review*. 2023. DOI: 10.3389/fpubh.2023.999958 (cit. on p. 11).

[58] N. Dasgupta and F. Kapadia. *The Future of the Public Health Data Dashboard*. 2022-06. DOI: 10.2105/AJPH.2022.306871 (cit. on p. 11).

[59] R. Hong et al. *The power of public health surveillance*. 2020. DOI: 10.32481/djph.2020.07.016 (cit. on p. 12).

[60] I. H. Sarker. *Machine Learning: Algorithms, Real-World Applications and Research Directions*. 2021-05. DOI: 10.1007/s42979-021-00592-x (cit. on p. 12).

[61] S. I. Ranapurwala et al. "Public health application of predictive modeling: An example from farm vehicle crashes". In: *Injury Epidemiology* 6 (1 2019-06). ISSN: 21971714. DOI: 10.1186/s40621-019-0208-9 (cit. on p. 13).

[62] V. Mhasawade, Y. Zhao, and R. Chunara. *Machine learning and algorithmic fairness in public and population health*. 2021-08. DOI: 10.1038/s42256-021-00373-4 (cit. on p. 13).

[63] P. M. Rodrigues, J. P. Madeiro, and J. A. L. Marques. *Enhancing Health and Public Health through Machine Learning: Decision Support for Smarter Choices*. 2023-07. DOI: 10.3390/bioengineering10070792 (cit. on p. 13).

[64] V. Plevris et al. "Investigation of Performance Metrics in Regression Analysis and Machine Learning-Based Prediction Models". In: Scipedia S.L., 2022. DOI: 10.23967/eccomas.2022.155 (cit. on pp. 13, 14).

[65] A. Botchkarev. "Performance Metrics (Error Measures) in Machine Learning Regression, Forecasting and Prognostics: Properties and Typology". 2018 (cit. on p. 13).

[66] D. Chicco, M. J. Warrens, and G. Jurman. "The coefficient of determination R-squared is more informative than SMAPE, MAE, MAPE, MSE and RMSE in regression analysis evaluation". In: *PeerJ Computer Science* 7 (2021), pp. 1–24. ISSN: 23765992. DOI: 10.7717/PEERJ-CS.623 (cit. on p. 13).

[67] K. Stewart. *Mean Squared Error (MSE): Definitio, Formula, Interpretation, Facts*. 2023. URL: https://www.britannica.com/science/mean-squared-error (cit. on p. 14).

[68] T. Chai and R. R. Draxler. "Root mean square error (RMSE) or mean absolute error (MAE)? -Arguments against avoiding RMSE in the literature". In: *Geoscientific Model Development* 7 (3 2014-06), pp. 1247–1250. ISSN: 19919603. DOI: 10.5194/gmd-7-1247-2014 (cit. on p. 14).

[69] P. Schneider and F. Xhafa. "Chapter 3 - Anomaly detection: Concepts and methods". In: *Anomaly Detection and Complex Event Processing over IoT Data Streams*. Ed. by P. Schneider and F. Xhafa. Academic Press, 2022, pp. 49–66. ISBN: 978-0-12-823818-9. DOI: https://doi.org/10.1016/B978-0-12-823818-9.00013-4. URL: https://www.sciencedirect.com/science/article/pii/B9780128238189000134 (cit. on p. 14).

[70] R. Gill. *What is Open-Source Intelligence?* 2023-02. URL: https://www.sans.org/blog/what-is-open-source-intelligence/ (cit. on p. 17).

[71] *Handbook on simulation exercises in EU public health settings*. 2014-05. DOI: 10.2900/35657. URL: www.ecdc.europa.eu (cit. on p. 18).

[72] A. Vabalas et al. "Machine learning algorithm validation with a limited sample size". In: *PLoS ONE* 14 (11 2019-11). ISSN: 19326203. DOI: 10.1371/journal.pone.0224365 (cit. on p. 20).

[73] DGS. *Resposta Sazonal em Saúde – Vigilância e Monitorização*. https://covid19.min-saude.pt/resposta-sazonal-em-saude-vigilancia-e-monitorizacao/. Accessed on 23/04/2023 (cit. on p. 24).

[74] E. Afrifa-Yamoah et al. "Missing data imputation of high-resolution temporal climate time series data". In: *Meteorological Applications* 27 (1 2020-01). ISSN: 14698080. DOI: 10.1002/met.1873 (cit. on p. 25).

[75] C. Sax and P. Steiner. *Temporal Disaggregation of Time Series*. 2013-12 (cit. on p. 25).

[76] *Guide to multi-criteria analysis Technical guide of the Assessment Framework*. 2021-07. ISBN: 9781925352542 (cit. on p. 27).

[77] M. da Saúde and D. G. da Saúde. *Plano de Contingência Saúde Sazonal - Módulo Verão Referenciais 2023*. 2023. URL: https://www.sns.gov.pt/resposta-sazonal-em-saude-verao/ (cit. on p. 30).

[78] M. da Saúde and D.-G. da Saúde. *Plano de Contingência Saúde Sazonal - Módulo Verão Referenciais 2022*. 2022. URL: www.dgs.pt (cit. on p. 30).

[79] M. da Saúde and D.-G. da Saúde. *Plano de Contingência Saúde Sazonal - Módulo Verão Referenciais 2021*. 2021. ISBN: 9789726753216. URL: www.dgs.pt (cit. on p. 30).

[80] D. G. da Saúde. *Plano Nacional de Prevenção e Controlo de Doenças Transmitidas por Vetores*. 2016 (cit. on p. 30).

[81] C. M. do Sabugal. *Plano de Contingência para Água em Situações de Seca Agrometeorológica Extrema do Concelho Sabugal*. 2022. URL: https://www.cm-sabugal.pt/camara-municipal/ambiente/plano-de-contingencia-para-agua-em-situacoes-de-seca-agrometeorologica-extrema-do-concelho-sabugal/ (cit. on p. 30).

[82] A. P. do Ambiente. *Plano de Prevenção, Monitorização e Contingência para Situações de Seca*. 2017. URL: https://apambiente.pt/agua/plano-de-prevencao-monitorizacao-e-contingencia-para-situacoes-de-seca (cit. on p. 30).

[83] A. N. de Proteção Civil. *Planos de Emergência de Protecção Civil*. URL: http://planos.prociv.pt/Pages/homepage.aspx (cit. on p. 30).

[84] P. Civil and C. M. de Lisboa. *Plano Municipal de Emergência de Proteção Civil de Lisboa*. 2017 (cit. on p. 30).

[85] C. de Gestão do Plano do Ministério da Saúde Para a Jornada Mundial da Juventude. *Ações de Preparação e Resposta do Ministério da Saúde para a JMJ*. 2023. URL: https://www.sns.gov.pt/jmj/plano-do-ministerio-da-saude-para-jmj2023/ (cit. on p. 30).

[86] C. de Estudos de Vetores e Doenças Infeciosas Doutor Francisco Cambournac. *REVIVE 2021 - Culicídeos e Ixodídeos : Rede de Vigilância de Vetores*. 2022. URL: www.insa.pt (cit. on p. 30).

[87] P. A. H. Organization and W. H. Organization. *Heatwaves: A Guide for Health-based Actions*. 2021. DOI: 10.37774/9789275124086. URL: https://doi.org/10.37774/9789275124086 (cit. on p. 30).

[88] W. H. O. R. O. for Europe. *Heat-health action plans: guidance*. Ed. by F. Matthies et al. World Health Organization, Europe, 2008. ISBN: 9789289071918 (cit. on p. 30).

[89] D. G. da Saúde. *SICO - Sistema de Informação de Certificados de Óbito*. URL: https://evm.min-saude.pt/ (cit. on p. 32).

[90] M. da Saúde. *Portal SNS Transparência*. URL: https://transparencia.sns.gov.pt/ (cit. on p. 32).

[91] A. P. do Ambiente. *QualAr: Informação sobre qualidade do ar*. 2023. URL: https://qualar.apambiente.pt/ (cit. on p. 32).

[92] F. F. M. dos Santos. *PORDATA: Estatísticas sobre Portugal e Europa*. 2023. URL: https://www.pordata.pt/ (cit. on p. 32).

[93] E. Weber et al. *The use of environmental scenarios to project future health effects: a scoping review*. 2023-07. DOI: 10.1016/S2542-5196(23)00110-9 (cit. on p. 37).

A

Predictive Heat-Health Model

Table A.1: Input environmental parameters for the developed predictive linear regression model, including units of measurement and original data source.

Input Parameter	**Units**	**Source**
Day	n.a.	n.a.
Month	n.a.	n.a.
Year	n.a.	n.a.
Maximum UV Index Class	Num	IPMA
Maximum UV Index	Num	IPMA
Average UV Index Class	Num	IPMA
Average UV Index	Num	IPMA
Average Temperature	$^{\circ}C$	IPMA
Maximum Temperature	$^{\circ}C$	IPMA
Minimum Temperature	$^{\circ}C$	IPMA
Average Wind Direction	$^{\circ}$	IPMA
Average Wind Intensity	m/s	IPMA
Ozone	$\mu g/m^3$	APA (QualAr)
Nitrogen Dioxide	$\mu g/m^3$	APA (QualAr)
Carbon Monoxide	mg/m^3	APA (QualAr)
Sulfur Dioxide	$\mu g/m^3$	APA (QualAr)
Particles < 10 µm	$\mu g/m^3$	APA (QualAr)
Particles < 2.5 µm	$\mu g/m^3$	APA (QualAr)

Table A.2: Output mortality parameters for the developed predictive linear regression model, including units of measurement and original data source.

Output Parameter	**Units**	**Region**	**Source**
Local Unknown Death	Num	Portugal	SICO-eVM
Health Institution Death	Num	Portugal	SICO-eVM
Home Death	Num	Portugal	SICO-eVM
Other Location Death	Num	Portugal	SICO-eVM
Natural Death	Num	Portugal	SICO-eVM
External Cause Death	Num	Portugal	SICO-eVM
Death Under Investigation	Num	Portugal	SICO-eVM
Death < 1 year	Num	Portugal	SICO-eVM
Death 1-4 years	Num	Portugal	SICO-eVM
Death 5-14 years	Num	Portugal	SICO-eVM
Death 15-24 years	Num	Portugal	SICO-eVM
Death 25-34 years	Num	Portugal	SICO-eVM
Death 35-44 years	Num	Portugal	SICO-eVM
Death 45-54 years	Num	Portugal	SICO-eVM
Death 55-64 years	Num	Portugal	SICO-eVM
Death 65-74 years	Num	Portugal	SICO-eVM
Death 75-84 years	Num	Portugal	SICO-eVM
Death > 85 years	Num	Portugal	SICO-eVM
Unknown Age Death	Num	Portugal	SICO-eVM
Portugal Total Mortality	Num	Portugal	SICO-eVM
LVT Mortality	Num	ARS LVT	SICO-eVM
Emergency Calls	Num	Portugal	SICO-eVM

Table A.3: Output health parameters for the developed predictive linear regression model, including units of measurement and original data source.

Output Parameter	**Units**	**Region**	**Source**
Activation of HELIMED Helicopters	Num	Portugal	INEM
Activation of VMER Vehicles	Num	Portugal	INEM
Activation of TIP Ambulances	Num	Portugal	INEM
Activation of SIV Ambulances	Num	Portugal	INEM
Activation of AEM Ambulances	Num	Portugal	INEM
Activation of MEM Motorcycles	Num	Portugal	INEM
Activation of UMIPE Mobile Unit	Num	Portugal	INEM
Activation of PEM Emergency Ambulances	Num	Portugal	INEM
Activation of RES Emergency Ambulances	Num	Portugal	INEM
Activation of NINEM Ambulances	Num	Portugal	INEM
ICARO Index	Num	Portugal	INSA
Urgent Care CSH	Num	ARS LVT	ACSS
Urgent Care with Hospitalization CSH	%	ARS LVT	ACSS
Urgent Care Priority Green or Blue CSH	%	ARS LVT	ACSS
Average Wait Time between Triage and Observation CSH	Minutes	ARS LVT	ACSS
Respiratory Infection Urgencies Rate CSH	%	ARS LVT	ACSS
Consultations CSP	Num	ARS LVT	ACSS
Unprogrammed Consultations CSP	Num	ARS LVT	ACSS
Programmed Consultations CSP	Num	ARS LVT	ACSS
Unprogrammed Consultations CSP >=65 years	Num	ARS LVT	ACSS

B

Heatwave Scenario

Location: Lisbon and Tagus Valley Region, Portugal

Year: 2025

Context:

As winter ended in Portugal, the land was dry due to scarce rainfall. Rivers shrank and fields turned brown. Portuguese people anticipated the coming spring, uncertain if it would bring relief or more challenges.

In spring, the country experienced unexpected warmth that caused high temperatures. Instituto Português do Mar e da Atmosfera (IPMA) monitored these changes, as temperatures continued to rise. People went to the beach to cool off, but the heat waves persisted and disrupted daily life.

In Portugal, the intense summer heat caused distress as landscapes suffered from drought. The mortality rate rose as hospitals struggled to cope with heat-related illnesses, and healthcare professionals were on vacation.

Module 1 – Heatwave Alert

7/1/25 6:00

Inject 1 - IPMA

On July 1st, 2025, at 6:00 AM, IPMA detected an impending heatwave of unprecedented magnitude starting on the 3rd of July. The forecast was dire – seven consecutive days with temperatures soaring beyond 40°C.

Decision 1.1.1 (7/1/25 6:15): Should the collaborators that took notice of this concern contact the head of department at IPMA now or wait until 9 a.m.?

A. Option A: Immediately contact the responsible.

B. Option B: Allocate part of the resources to prepare a report on the issue.

C. Option C: Wait until 9 am to tackle the issue.

   Explanation: Option A is the better choice here as it prioritises swift action and ensures that the responsible parties are informed promptly. In an impending heatwave, prompt communication is crucial to initiate preparations.

Decision 1.1.2 (7/1/25 9:00): The responsible person is immediately informed upon arrival and asks for a report on predictions and impact.

A. Allocate all resources to prepare the report.

B. Allocate 70% of the team to prepare the report and 30% to contact other authorities.

Explanation: Option A is the more effective choice as it focuses on the immediate preparation of a comprehensive report, allowing for a thorough understanding of the situation before taking further actions.

A report with predictions for the next 15 days and impact expectations is finalised. As expected, the forecast is concerning: 7 days of temperatures above 40°C with the lowest temperatures only reaching 25°C. The humidity levels pose health risks as they swing between low and high extremes. The sun's ultraviolet rays are particularly intense, registering a high UV index that adds to the challenges. IPMA needs to assess and activate appropriate alert levels. The transition from yellow to orange to red would offer citizens a clear understanding of the escalating danger.
Decision 1.1.3 (7/1/25 11:00): A heatwave is already occuring, so an IPMA yellow alert level is currently active. Should it be revised now or later?

A. Option A: Activate Orange Alert level.
B. Option B: Maintain Yellow Alert level.
C. Option C: Activate Red Alert level.
D. Option D: Activate Green Alert level.

Explanation: Option A is the better choice as it acknowledges the escalating danger of the upcoming extreme heat wave by raising the alert level to orange. This ensures that citizens are adequately informed about the increased risk.

7/1/25 16:00
Inject 2 – ANEPC and DGS

After a meeting with the responsible at IPMA, ANEPC and DGS are briefed on the situation and predictions. These entities collaborate to ensure the population's safety during heatwave periods (ANEPC issues warnings and alerts related to the heatwave, while the DGS provides public health guidance to assist people in coping with extreme heat conditions).
Decision 1.2.1 (7/1/25 16:00): In preparation for a heatwave, information campaigns should be conducted to inform and prepare the population. What campaign/campaigns should be prepared? (submit up to 10 terms)

Key terms: Drought, Ventilation, Car, Home, Outdoor workers, Companies/Employers, Hydration, Beach/Outdoor activities, Chronic Illnesses, Elders

MOBILIZAR AS PESSOAS COMO QUANDO? DESTINO

A. Open answer: Refers to 9 or 10 terms
B. Open answer: Refers 7 or 8 terms

C. Open answer: Refers 5 or 6 terms

D. Open answer: Refers 4 or less terms

- Drought Prevention Campaign – educate the public about the importance of water conservation to prevent droughts. It encourages responsible water use in daily life, efficient landscaping practices, and community-based initiatives to safeguard our water resources.
- Hydration Campaign – (health) emphasises the significance of proper hydration, especially during hot weather. It offers practical tips on staying adequately hydrated throughout the day and recognising the signs of dehydration.
- Chronic Illness Awareness Campaign – tailored to individuals with chronic conditions, guides managing health during extreme weather conditions. Includes strategies for adapting to weather-related challenges, understanding the impact of weather on medication, and accessing community support for improved well-being.
- Home Heat Safety Campaign – shades, curtains, or blinds, and avoiding the use of heat-producing appliances during the hottest parts of the day
- Car Safety in Hot Weather – Emphasize the dangers of leaving children or pets in hot cars and provide guidelines for keeping vehicles cool during extreme heat
- Ventilation Campaign – recommendations on when and how to ventilate homes and workplaces to prevent overheating
- Outdoor Workers Safety Campaign – guidance to outdoor workers on how to protect themselves from heat-related illnesses, such as staying hydrated, taking breaks in the shade, and wearing appropriate clothing
- Outdoor Activities Campaign – how to safely do activities outside during a heatwave, including staying hydrated, avoiding strenuous activities during peak heat hours, and using sunscreen
- Heatwave Awareness for Employers – would outline the responsibilities of employers in ensuring worker safety during extreme heat, including providing adequate breaks and shade

Decision 1.2.2 (7/2/25 14:00): As the communications team is working on campaigns, the other members of ANEPC should get in touch with the remaining authorities. What measures should be put in place by the Fire Departments in the AML and INEM to prepare for fire risk management and emergency response coordination?

A. Immediately prepare Alerts and Restrictions on Land Clearances, Barbecues, and Fireworks. Monitor and assess the heatwave's intensity and severity before implementing other measures.

B. Promptly enhance Preparedness and Resource Allocation. Initiate immediate Alerts and Restrictions on Land Clearances, Barbecues, and Fireworks.
C. Immediately enhance Preparedness and Resource Allocation. Monitor and assess the heatwave's intensity and severity before implementing other measures.
D. Monitor and assess the heatwave's intensity and severity before implementing any measures.

Explanation: Option A is the better choice as it emphasises immediate action to enhance preparedness, initiate alerts, and impose restrictions to mitigate fire risk. Timely measures can prevent potential disasters, but according to the real evolution of the situation, these resources can be necessary for further complications.

Decision 1.2.3 (7/2/25 14:00): A meeting takes place with ANEPC, the Regional Tourism Entity of the Lisbon Region (ERTRL), AMN, and FPNS. What strategies are needed to ensure the safety and well-being of tourists and residents during the heatwave?

A. Increase the number of beach lifeguards and await a report on tourism occupancy in the AML to take measures.
B. Increase the number of beach lifeguards and begin intervention in the AML central areas.
C. Maintain the current number of beach lifeguards and await a report on tourism occupancy in the AML.

Explanation: Option A is the better choice as it prioritises immediate safety enhancement by increasing lifeguards and preparing to act in touristic areas. Safety measures should be initiative-taking during a heatwave to protect both residents and tourists, and even a quick assessment should allow for more efficient measures.

Decision 1.2.4 (7/2/25 09:00): DGS works with hospitals and primary care to adapt services during the heatwave. Which measures should be prioritised?

A. Expand service hours to avoid peak heat periods and increase urgent care capacity.
B. Establish cooling centres in healthcare facilities for patients with heat-related illnesses.
C. Develop a telemedicine program for remote heat-related health consultations.

Explanation: Option A is the primary measure, focusing on timely care and expanded capacity. Option C, while applicable, may not fully address the urgent care needs during extreme heat. Option B is moderately good, providing comfort for patients. Ideally, the health services should focus on emergencies. Chronic care critical situations should be prioritised (telemedicine services should be used in large scale to avoid people to move around) and routine consultations postponed.

Decision 1.2.5 (7/2/25 14:00): DGS collaborates with INFARMED and Pharmacies to ensure medication availability during the heatwave. What should be the focus?

A. Confirm and adjust medication stock in hospital and community pharmacies based on heat-related health needs.
B. Launch a public awareness campaign about proper medication storage during extreme heat.
C. Facilitate the delivery of essential medications to vulnerable populations.

Explanation: Option A is the primary focus, ensuring medication availability for at-risk patients. Option B is a valuable secondary measure for medication safety. Option C, while applicable, may not address medication stock.

Decision 1.2.6 (7/3/25 09:00): ANEPC is working with CML and associations to define protective measures for the homeless and elderly, as a final preparation for the challenging days ahead.

A. Activate temporary shelter locations immediately.
B. Monitor weather conditions and assess the need.
C. Explore alternative solutions, such as partnerships with local businesses or institutions.

Explanation: Option A is the better choice in this scenario. Activating temporary shelter locations immediately is a proactive and practical step to ensure the safety and well-being of homeless and elderly individuals during extreme heat waves. It provides a tangible, direct solution to protect vulnerable groups from heat-related risks. Option C is valuable but might take longer to implement and may not address the immediate needs of these vulnerable populations. Option B is necessary but may not guarantee timely assistance in sudden heatwaves.

Decision 1.2.7 (7/3/25 09:00): DGS responding to heat-related illnesses. What strategy should be implemented?

A. Deploy mobile healthcare units near beaches tailored to specific medical conditions.
B. Launch a mobile health app providing real-time heat-related health information and tips.

C. Distribute heat safety kits with information and supplies to vulnerable populations.

Explanation: Option A is the recommended strategy, providing immediate on-site care for those in need. Option B is moderately good as it uses technology for information dissemination. Option C, while well-intentioned, may not address immediate health concerns.

Decision 1.2.8 (7/4/25 09:00): DGS collaborates with Tropical Medicine Institute to adress vector-borne diseases in warmer conditions. What actions should be taken?

A. Implement mosquito control measures in high-risk areas to mitigate the spread of diseases.
B. Conduct public health campaigns on preventing vector-borne diseases during heatwaves.
C. Expand research on new treatment methods for heat-related vector-borne illnesses.

Explanation: Option A is the recommended action, directly addressing disease prevention and keeping track of vector-borne diseases numbers. Option B contributes to public awareness but is not as direct. Option C, while necessary, may not immediately impact disease control during the heatwave.

Module 2 – Drought
7/3/25 17:00
Following an extensive day of deliberation and assessment, it has been officially declared by ERSAR (Entidade Reguladora dos Serviços de Águas e Resíduos) that the Municipalities of Sintra, Oeiras, and Lisboa are in a critical state of drought. This dire situation has arisen due to a significant decrease in precipitation levels and a consequential shortage of vital hydric resources.

Decision 2.1 (7/6/25 09:30): With the official declaration of drought, coordinated actions must be taken to manage the water crisis effectively. What immediate steps should be taken to address this critical drought situation?

A. Implement water consumption restrictions, including limits on garden irrigation, car washing bans, or the introduction of differentiated tariffs.
B. Launch a comprehensive public awareness campaign to inform the population about responsible water use and recycling practices.
C. Organize resources to respond to potential wildfires adequately, provide a stable potable water supply, and support affected communities.

Explanation: Option A is the most effective response to drought as it addresses water conservation. Implementing water consumption restrictions helps preserve limited water resources, ensuring there is enough for essential needs.

Option B also plays a crucial role in raising awareness, but immediate action is required. Option C, while necessary, focuses more on emergency preparedness than direct conservation efforts.

Decision 2.2 (7/6/25 15:00): To enforce the chosen measures effectively, involving relevant authorities and agencies is crucial. How should the implementation of drought management measures be coordinated?

A. Collaborate with the Entidade Gestora de Abastecimento de Água (Water Supply Management Entity) to enforce water consumption restrictions, policies, and tariffs.
B. Restructure the general organisation of resources, ensuring an adequate supply of resources to combat forest fires, tackle the scarcity of potable water, and maintain supply in affected communities.
C. Engage with ANEPC to communicate the imposed limits and restrictions to the population and consumers, guiding water conservation and recycling.

Explanation: Option A is the recommended approach as it directly deals with water resource management and enforcing consumption restrictions. Option C complements public awareness efforts, and Option B, while necessary, focuses more on emergency response.

Decision 2.3 (7/6/25 18:00): Effective communication is crucial when implementing drought management measures. How should the communication of restrictions be handled, in order to ensure they are conveyed sensitively and clearly?

A. Communicate limits and restrictions directly to the population and consumers, emphasising the importance of water conservation and recycling.
B. Focus on disseminating information on saving water and engaging in recycling through public awareness campaigns.
C. Prioritize communication of the imposed limits and restrictions without detailed water conservation or recycling guidance.

Explanation: Option A is the recommended approach as it combines clear communication of restrictions with an emphasis on water conservation. Option B promotes awareness but may not address immediate needs. Option C lacks detailed guidance on preservation.

Decision 2.4 (7/7/25 10:00): Ensuring the availability of necessary resources and effective response to drought management challenges is critical. How should resources be organized to address the situation?

A. Organize resources to ensure an adequate supply for firefighting efforts, maintain a stable potable water supply, and support communities affected by the drought.

B. Focus on ensuring sufficient resources for firefighting efforts, with minimal emphasis on maintaining potable water supply or community support.

C. Allocate resources primarily for maintaining potable water supply, with limited consideration for firefighting efforts or community support.

Explanation: Option A is the recommended approach as it prioritises a well-rounded response to the challenges posed by drought. Options B and C, while necessary, may not address all critical needs adequately.

Decision 2.5 (7/8/25 15:00): The ongoing drought requires close monitoring and preparation for potential complications. What measures should be taken to address the specific challenges hospitals face, especially considering the potential for water shortages?

A. Develop a contingency plan for hospitals to address water shortages, including prioritising critical healthcare services.

B. Implement water-saving measures in hospitals, such as reducing non-essential water usage and optimising water recycling systems.

C. Collaborate with local authorities to ensure hospitals receive a stable water supply from alternative sources to mitigate potential shortages.

Explanation: Option A is the recommended approach as it addresses the potential water shortage issue in hospitals by preparing a comprehensive contingency plan. Option B is also valuable for immediate water conservation efforts, but Option B focuses more on external support.

Decision 2.6 (7/8/25 16:00): What actions should be taken to support agricultural communities facing water scarcity and crop loss during the critical drought situation?

A. Collaborate with agricultural organisations to implement water-efficient irrigation practices and support sustainable farming techniques.

B. Establish emergency relief centres for affected farmers to provide food, water, and temporary shelter.

C. Provide financial assistance and subsidies to affected farmers to help them cope with crop losses and maintain livelihoods.

Explanation: Option A is recommended as it focuses on long-term solutions by promoting sustainable farming techniques and efficient water use. Option B and Option C are necessary for immediate support but may not address the root causes.

Decision 2.7 (7/9/25 09:00): As the drought persists, additional measures are necessary to provide potable water for affected communities. What relevant steps should be taken?

A. Implement water rationing and distribution systems to ensure equitable access to drinking water for all affected communities.
B. Launch a public awareness campaign on responsible water use and conservation to reduce the demand for potable water.
C. Collaborate with neighbouring regions to secure additional water supplies and transport them to the affected areas.

Explanation: Option A is the recommended approach as it directly addresses the challenge of potable water scarcity by implementing rationing and distribution systems. Option C is valuable for securing additional supplies, but coordinating may take time. Option B complements the efforts but does not provide an immediate solution to water scarcity.

Decision 2.8 (7/9/25 09:00): What actions can be taken to support communities managing drought, particularly those without access to centralized water supplies?

A. Establish community water collection points equipped with water tanks and purification systems for easy access to clean water.
B. Collaborate with local NGOs to distribute water purification kits and provide training on water treatment methods.
C. Organize community workshops on rainwater harvesting techniques and provide the necessary materials for implementation.

Explanation: Option A is recommended to ensure immediate access to clean water for communities without centralised supplies. Option B and Option C are necessary for long-term sustainability but may not provide immediate relief.

Module 3 – Air Quality
7/11/25 17:00
IPMA reports an increase in pollen levels, intense winds, and African dust particles, severely impacting air quality. Additionally, the heatwave has lasted longer than expected.
Decision 3.1 (7/11/25 09:00): With flights already being cancelled because of low visibility, what actions should be taken in response to this concerning air quality situation?

A. Prepare teams and notify the public about the deteriorating air quality, providing specific data and recommendations.
B. Implement measures to limit outdoor activities, especially for vulnerable groups.
C. Monitor the situation closely without immediate action, as these conditions are uncommon in Portugal.
D. Initiate a study to assess the long-term impact of these unusual air quality conditions.

Explanation: Option A is recommended as it focuses on immediate communication and transparency regarding air quality data and precautions. Option B is considered, but it's vital to prioritise information dissemination.

Decision 3.2 (7/11/25 12:00): IPMA collaborates with ANEPC to issue warnings regarding the deteriorating air quality. What additional relevant data and actions should be included in these warnings?

A. Provide comprehensive data on the air quality situation, including relevant statistics, trends and guidance on mitigating the effects.

B. Coordinate with the Ministry of Education to implement measures to protect students and staff in schools and universities.

C. Collaborate with APA (Agência Portuguesa do Ambiente) to gather additional information and recommendations for reducing air quality.

D. Collaborate with local authorities to distribute air purifiers and masks to vulnerable populations while activating initiatives to monitor air quality at the neighbourhood level.

Explanation: Option A is the recommended approach as it ensures that the warnings are as informative as possible, equipping the public with accurate data and guidelines on protecting themselves during poor air quality conditions. Option B can be considered correct with the right arguments because, although necessary, it requires more logistics and may not be as urgent. Option C could be considered for its potential to provide additional insights. Option D, while necessary, focuses more on preparedness than immediate efforts.

ACSS reports an increase in hospitalisations among children and the elderly, likely linked to the deteriorating air quality. DGS anticipated the situation and has prepared measures to address the rise in hospitalisations, reflecting proactive planning and preparedness for health-related issues associated with poor air quality.
Decision 3.3 (7/12/25 19:00): Considering the escalating air quality concerns the Ministry of Education and DGS are considering closing schools and daycare centres. What additional benefits or effects should be considered when making this decision?

A. Closing schools and daycare centres is recommended to reduce road traffic and protect at-risk groups exposed to vector-borne diseases.

B. Rather than closing schools, collaborate with the Ministry of Education and Social Security to provide educational resources and financial support to families affected by health-related conditions.

C. Closing schools and daycare centres is not ideal due to the impact on parents and caregivers, necessitating flexibility, such as teleworking options.

Explanation: Option A is recommended as it highlights the broader benefits of reducing traffic and protecting vulnerable groups. Option C acknowledges the need for flexibility but doesn't prioritise these factors. Option B is remarkable but would not have a direct effect in reducing impact.

Decision 3.4 (7/12/25 19:30): As a follow-up to the possible school and daycare closures, communication regarding teleworking options for parents and caregivers would be essential. What approach should be taken to communicate this to the affected individuals?

A. Communicate clear teleworking guidelines and policies for employers so children's well-being is ensured with flexibility for parents and caregivers.
B. Communicate teleworking options focusing solely on remote work arrangements' availability and requiring immediate adjustment.
C. Coordinate with local businesses to provide childcare support for parents and caregivers during work hours.

Explanation: Option A is the recommended approach as it balances the need to communicate teleworking options with the importance of flexibility for caregivers and employers.

Decision 3.5 (7/13/25 16:00): Besides the immediate response, it would be essential to consider measures for remote healthcare and mental health support due to the ongoing air quality issues. What strategies should be prioritised?

A. Prioritize telemedicine and remote healthcare services to ensure ongoing access to medical support during this period.
B. Collaborate with healthcare providers to establish mobile clinics and outreach programs to reach vulnerable populations affected by poor air quality.
C. Initiate a mental health awareness campaign, providing resources for individuals experiencing stress and anxiety related to the ongoing air quality issues.

Explanation: Option A is recommended as it combines telemedicine and mental health support, addressing physical and mental health needs. Option C is valuable given that it can be prepared parallelly, but due to the conditions for the past weeks and workers on vacation, it may not be possible. Option B would take a longer time to prepare.

Decision 3.6 (7/14/25 14:00): As the air quality situation persists, measures must be implemented to ensure the availability of clean air. What steps should be taken to mitigate the impact of the extended poor air quality?

A. Collaborate with environmental agencies to monitor air quality and take immediate actions to reduce pollution sources.

B. Conduct a public awareness campaign to encourage individuals to reduce activities contributing to poor air quality.
C. Implement strict industrial emissions and vehicular traffic regulations to minimise air pollution.
D. Provide financial incentives to promote the use of electric vehicles and reduce air pollution.

Explanation: Option A is recommended as it combines monitoring and immediate action to address pollution sources. Option B is also recommended as a rapid spread of information could improve air quality in homes and reduce impacts.

Module 4 - Localized Severe Weather Conditions
7/11/25 14:00

On the 11th of July, 2025, at 2:00 PM, IPMA detected an impending severe weather event characterised by heavy rainfall, thunderstorms, strong winds, and the possibility of hail localised in the center of Lisbon and Almada. This event could lead to floods, posing risks to homes and healthcare facilities. This situation arises following extreme drought and differs from tropical rainfall due to its association with weather instability, fronts, or low-pressure areas.

Decision 4.1 (7/16/25 14:00): Given the forecasted severe weather conditions, what level of weather alert should be issued to inform the population about this unique weather event?

A. Issue an Orange Weather Alert, emphasising the new climate-related concern.
B. Activate a Yellow Weather Alert to raise awareness.
C. Declare a Red Weather Alert, signalling extreme weather conditions.

Explanation: Option A is the recommended approach. Issuing an Orange Weather Alert that underscores the connection to climate change alerts the population and communicates the broader context. Option B may not convey the seriousness of the situation, while Option C might be seen as overly alarming given the specific circumstances.

Decision 4.2 (7/17/25 09:00): As the rainfall event unfolds, it's crucial to take immediate action to address potential flooding and ensure the safety of affected individuals. What steps should be taken regarding drainage and flood management?

A. Prioritize drainage and flood management efforts in areas prone to flooding.
B. Activate local response teams and emergency services to assist with drainage and flood mitigation.

C. Deploy mobile flood barriers and pumps in flood-prone areas to prevent further damage.

D. Collaborate with relevant agencies to assess the extent of flooding and plan for evacuations if necessary.

Explanation: Option A is recommended as it tackles drainage and flood management in vulnerable areas, directly addressing the issue. Options B and C, although necessary, involve resource-intensive measures that may not be immediately necessary (especially C). Option D is relevant but should be considered after addressing immediate needs.

Decision 4.3 (7/17/25 14:00): In the event of localised flooding in homes or healthcare facilities, it's crucial to ensure the safety and well-being of the affected individuals. What measures should be implemented to address healthcare needs and support those affected by flooding?

A. Establish dedicated healthcare teams to assist flood-affected individuals, particularly the elderly and those with chronic illnesses.

B. Initiate the relocation of families affected by flooding to safe locations, such as designated shelters in Leiria, Setúbal, or Santarém.

C. Ensure the availability and distribution of necessary medications to individuals in flood-affected areas and at temporary shelter locations.

Explanation: Option A is the recommended approach, as it prioritises immediate medical assistance to those in need, focusing on concerning groups. Option B may be necessary, but relocation logistics can be complex and depend on the issue's evolution. Option C is important but should complement the primary healthcare response.

Decision 4.4 (7/19/25 07:00): After the heavy rainfall, Lisbon is in chaos, with public transportation disruptions, power outages, road closures, and water supply interruptions and contaminations. How should these challenges be addressed?

A. Coordinate efforts to restore power, clear blocked roads, and ensure a stable water supply while advising people to stay home and avoid unnecessary travel.

B. Communicate effectively with the public about the disruptions and provide alternative routes and transport options.

C. Implement contingency plans for public transportation and prioritise swift recovery of services.

Explanation: Option A is the recommended approach. Coordinating efforts to address power outages, road closures, and water supply issues directly tackles the immediate challenges posed by the severe weather conditions. Options B and C are relevant but should follow once critical infrastructure issues are resolved.

Decision 4.5 (7/20/25 16:00): In the wake of the thunderstorms and strong winds, the risk of wildfires due to lightning strikes increases. How should this potential wildfire situation be managed?

A. Activate firefighting teams and resources to combat wildfires caused by lightning and thunderstorms.

B. Collaborate with IPMA and the Fire Department to issue warnings and advisories regarding wildfire risk.

C. Deploy firefighting personnel and resources to high-risk areas prone to wildfires.

Explanation: Option A is the recommended approach, as it involves immediate action to combat wildfires resulting from lightning and thunderstorms. Option B is valuable for public awareness but may not directly address fire management, given these would be naturally caused fires. Option C, although important, should be considered in the context of broader firefighting efforts.

A wildfire in a critical situation near Lisbon, in a large Eucaliptus area in Loures, triggered by lightning strikes. The problem is severe and escalating rapidly. Firefighters and emergency responders are working tirelessly to control the blaze and ensure the safety of residents. Immediate actions are being taken to coordinate resources and combat wildfires effectively.

Decision 4.6 (7/21/25 12:00): The wildfire that broke out in a vulnerable area in Lisbon poses significant risks to nearby communities. How should this situation be managed to ensure the safety of the affected districts?

A. Collaborate with local authorities and firefighters from the area to establish containment lines and control the wildfire's spread by ground.

B. Activate a comprehensive emergency response plan, including evacuation procedures, to safeguard residents in high-risk areas.

C. Mobilize aerial firefighting resources, such as water-dropping helicopters, to combat the wildfire effectively.

D. Implement a public awareness campaign about wildfire safety and evacuation procedures, emphasising community preparedness.

Explanation: Option A is the recommended approach as it prioritises immediate measures for containment after the wildfire has started. Option B ensures the safety of residents in high-risk areas through well-defined evacuation procedures, but it is not immediate. Option D is valuable for long-term preparedness but may not address the primary threat. Option C is relevant but should complement ground-based firefighting efforts.

Decision 4.7 (7/22/25 10:00): The wildfire situation in Lisbon remains critical, and additional measures are required to control and eventually extinguish the fire. What strategy should be prioritised for wildfire management?

A. Establish a command centre to coordinate firefighting efforts and allocate resources effectively.

B. Collaborate with neighbouring regions to secure additional firefighting resources and personnel.

C. Continue deploying ground and aerial firefighting resources to suppress the wildfire.

D. Evacuate residents from high-risk areas and implement controlled burns to mitigate the wildfire spread.

Explanation: Option A is the recommended approach as it focuses on effective coordination and resource allocation, which is critical in managing a wildfire situation. Option C is continuously happening, but a backstep is prudent and required to tackle the issue. Option B is relevant for resource augmentation. Option D, while an option, should be considered with caution due to its complexity and potential risks.

Decision 4.8 (7/23/25 14:00): The wildfire in Lisbon is gradually under control, but concerns remain about the impact on the local environment and air quality. What measures should be prioritised to address these environmental concerns?

A. Implement air quality monitoring to assess the health risks of smoke and particulate matter.

B. Establish a public information campaign to raise awareness about the environmental consequences of wildfires.

C. Collaborate with environmental agencies to assess the impact of the wildfire on local ecosystems and plan for habitat restoration.

Explanation: Option A is the recommended approach as it directly addresses the immediate concern of assessing health risks posed by smoke and particulate matter, ensuring public safety. Options B and C are valuable but should be part of a comprehensive post-fire recovery plan.

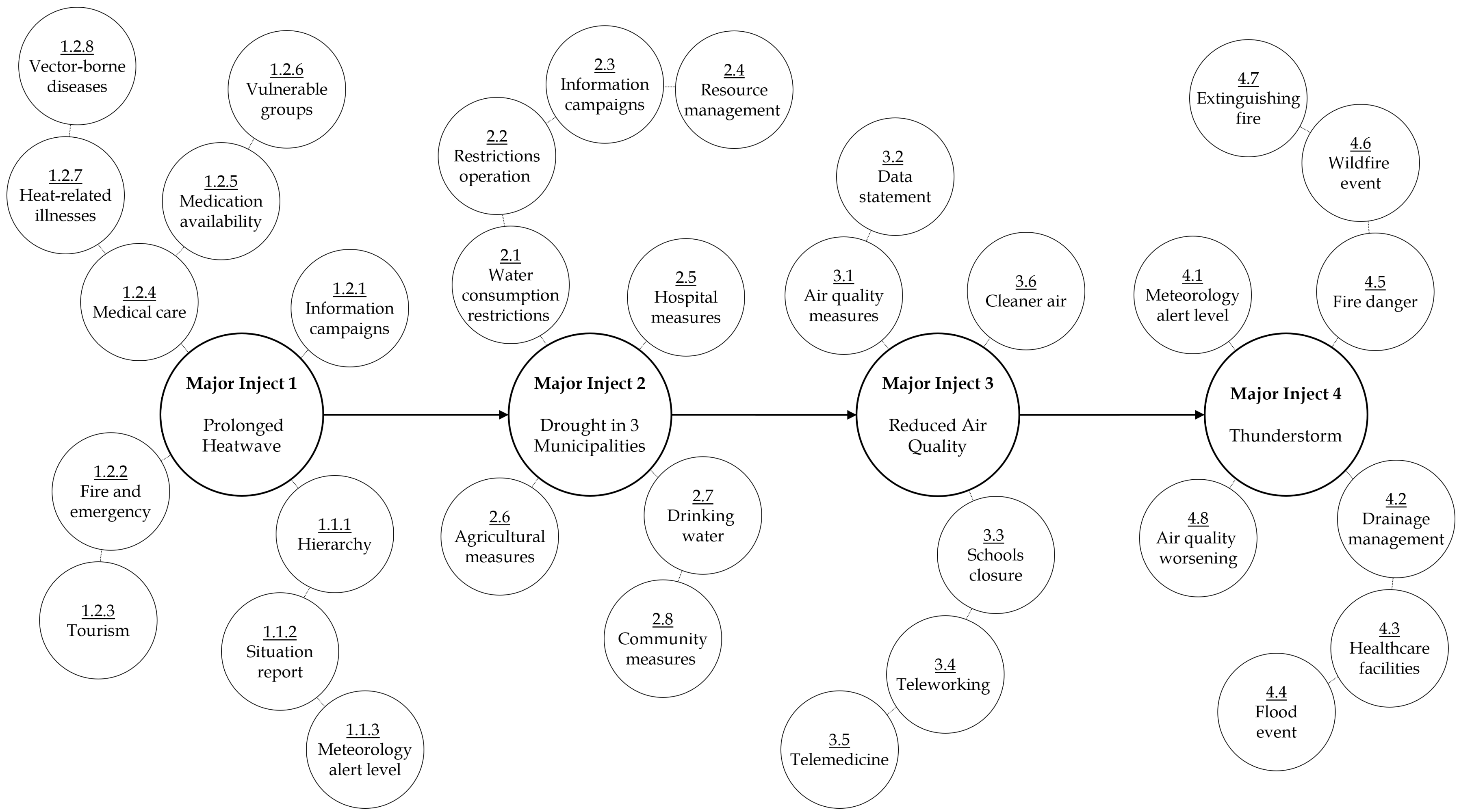

Figure B.1: Heatwave Storyline Schematic presents the four major injects and encompassed decision topics.

C

Correlation Analysis Results

Table C.1: Moderate correlations between UV index and health parameters in the decade of 2012-2022 in Lisbon, Portugal.

Granularity	r	P	Variable 1	Variable 2
Daily	-0.56	1.200e-240	UV Index	Total Mortality
Daily	-0.51	2.460e-193	UV Index	LVT Mortality
Daily	-0.52	9.164e-199	UV Index	Health Institution Deaths
Daily	-0.57	9.996e-252	UV Index	Home Deaths
Daily	-0.57	1.486e-252	UV Index	Natural Deaths
Daily	-0.54	3.526e-219	UV Index	75-84 y.o. Deaths
Daily	-0.57	5.225e-211	UV Index	Urgent Occurrences Respiratory Rate
Daily	-0.51	0.04543	UV Index	Flu Appointments
Weekly	-0.64	7.727e-49	UV Index	Total Mortality
Weekly	-0.62	7.928e-46	UV Index	LVT Mortality
Weekly	-0.61	2.156e-43	UV Index	Health Institution Deaths
Weekly	-0.70	6.168e-62	UV Index	Home Deaths
Weekly	-0.65	6.231e-52	UV Index	Natural Deaths
Weekly	-0.54	5.646e-33	UV Index	55-64 y.o. Deaths
Weekly	-0.59	2.575e-40	UV Index	65-74 y.o. Deaths
Weekly	-0.69	2.329e-59	UV Index	75-84 y.o. Deaths
Weekly	-0.57	1.328e-36	UV Index	> 85 y.o. Deaths

Table C.2: Strong and very strong correlations between UV index and health parameters in the decade of 2012-2022 in Lisbon, Portugal.

Granularity	Strength	r	P	Variable 1	Variable 2
Monthly	Strong	0.74	4.170e-8	UV Index	Spotted Fever (Rickettsiosis)
Monthly	Strong	0.81	4.458e-23	UV Index	Drowning/Diving*
Monthly	Strong	0.71	1.997e-15	UV Index	Aggression*
Monthly	Strong	0.75	1.084e-16	UV Index	Allergies*
Monthly	Very Strong	0.93	7.780e-5	UV Index	Medical Devices

* Pre-Hospital Occurences

Table C.3: Moderate correlations between mean temperatures and health parameters in the decade of 2012-2022 in Lisbon, Portugal.

Granularity	r	P	Variable 1	Variable 2
Daily	-0.57	0	Mean temperature	Total Mortality
Daily	-0.52	4.205e-229	Mean temperature	LVT Mortality
Daily	-0.53	3.592e-241	Mean temperature	Health Institution Deaths
Daily	-0.61	0	Mean temperature	Home Deaths
Daily	-0.59	0	Mean temperature	Natural Deaths
Daily	-0.55	1.899e-258	Mean temperature	75-84 y.o. Deaths
Daily	-0.52	3.265e-228	Mean temperature	> 85 y.o. Deaths
Daily	-0.53	3.778e-165	Mean temperature	Urgent Occurrences Respiratory Rate
Daily	-0.53	3.099e-160	Mean temperature	Flu Appointments
Weekly	-0.66	1.154e-73	Mean Temperature	Total Mortality

Table C.4: Strong correlations between mean temperatures and health parameters in the decade of 2012-2022 in Lisbon, Portugal.

Granularity	r	P	Variable 1	Variable 2
Monthly	0.89	4.610e-41	Mean Temperature	Drowning/Diving*
Monthly	0.81	1.054e-29	Mean Temperature	Aggression*
Monthly	0.74	1.036e-21	Mean Temperature	Allergies*
Monthly	-0.82	2.374e-15	Mean Temperature	Deaths CID 9 (Heart and Circulatory Problems)
Monthly	-0.76	1.777e-12	Mean Temperature	Deaths in Hospitals (CSH)
Monthly	-0.73	6.687e-10	Mean Temperature	Urgent Priority 1 Occurrences

* Pre-Hospital Occurences

Table C.5: Moderate correlations between air pollutants concentration and health parameters in the years of 2015-2022 in Lisbon, Portugal.

Granularity	r	P	Variable 1	Variable 2
Daily	-0.51	1.234e-115	Ozone	Flu Appointments
Daily	0.54	5.145e-141	Nitrogen Dioxide	Flu Appointments
Daily	0.55	1.928e-147	Nitrogen Oxide	Flu Appointments
Daily	0.58	1.541e-117	Benzene	Emergency Ambulances Activation
Daily	0.61	1.365e-134	Benzene	Emergency Rescue Ambulances Activation
Daily	0.50	5.006e-84	Benzene	Priority 1 Urgent Occurrences
Daily	0.57	3.369e-114	Benzene	Urgent Occurrences Respiratory Rate
Daily	0.67	2.901e-167	Benzene	Flu Appointments
Weekly	0.52	1.483e-20	Benzene	Home Deaths
Weekly	0.54	7.029e-23	Benzene	75-84 y.o. Deaths
Weekly	-0.53	2.391e-27	Sulfur Dioxide	Primary Healthcare Appointments
Weekly	-0.58	5.305e-34	Sulfur Dioxide	Non-Scheduled CSP Appointments
Weekly	-0.58	1.952e-34	Sulfur Dioxide	Non-Scheduled CSP Appointments >65 y.o.
Weekly	0.55	5.909e-30	Carbon Monoxide	Total Mortality
Weekly	0.56	1.713e-31	Carbon Monoxide	Health Institution Deaths
Weekly	0.56	4.865e-32	Carbon Monoxide	Home Deaths
Weekly	0.56	1.384e-31	Carbon Monoxide	Natural Deaths
Weekly	0.59	3.529e-35	Carbon Monoxide	75-84 y.o. Deaths

Table C.6: Strong correlations between air pollutants concentration and health parameters in the years of 2015-2022 in Lisbon, Portugal.

Granularity	r	P	Variable 1	Variable 2
Monthly	0.74	1.125e-6	Nitrogen Dioxide	Pediatric Emergencies
Monthly	0.70	9.990e-14	Sulfur Dioxide	Surgical Bed Occupancy
Monthly	-0.71	1.544e-5	Sulfur Dioxide	SNS24 Calls Transfered to Urgent Care
Monthly	-0.72	2.052e-14	Sulfur Dioxide	Psychiatric Problems/Suicide*
Monthly	-0.77	1.845e-17	Sulfur Dioxide	Hormonal Medication Expenses
Monthly	-0.77	8.116e-18	Sulfur Dioxide	Blood Medication Expenses
Monthly	-0.82	1.932e-21	Sulfur Dioxide	Total Telemedicine Appointments
Monthly	0.76	5.098e-17	Sulfur Dioxide	Diabetes*
Monthly	0.73	5.562e-15	Sulfur Dioxide	Without Manchester Triage
Monthly	0.73	2.297e-15	Nitric Oxides	Pediatric Emergencies
Monthly	0.72	1.454e-14	Nitric Oxide	Pediatric Emergencies

* Pre-Hospital Occurences

D

Situation Room Interfaces

Figure D.1: Final overview of the Tableau Dashboard considering worst decision-making procedures.

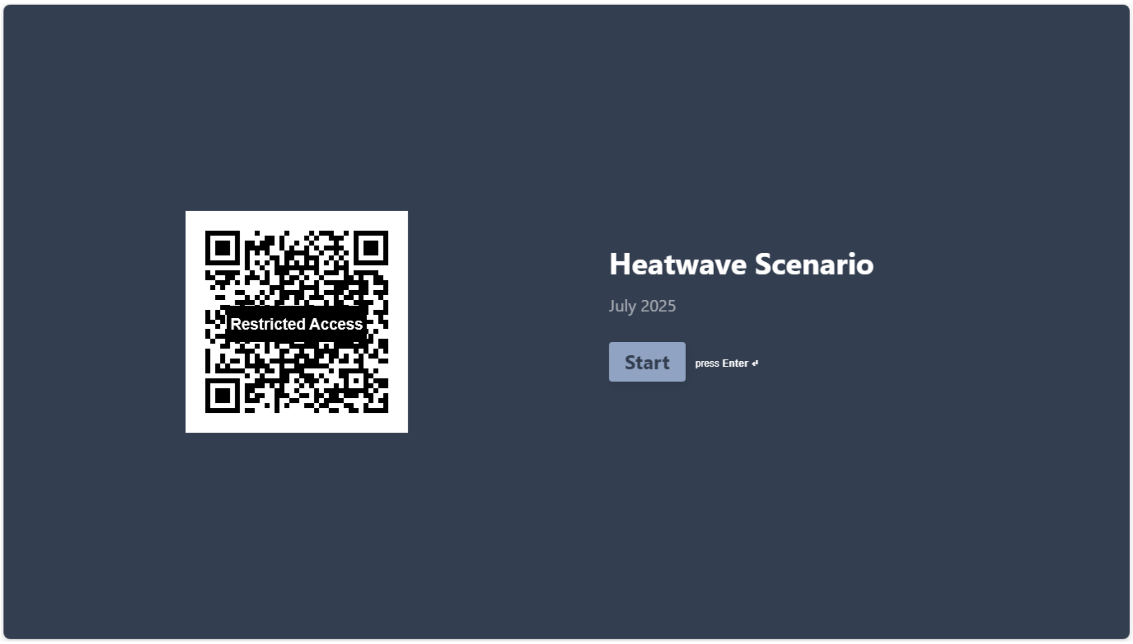

Figure D.2: Entry page of the Decision-Making platform developed using Typeform, featuring the day and month during which the simulation exercise takes place and a QR code for faster access via mobile phone.

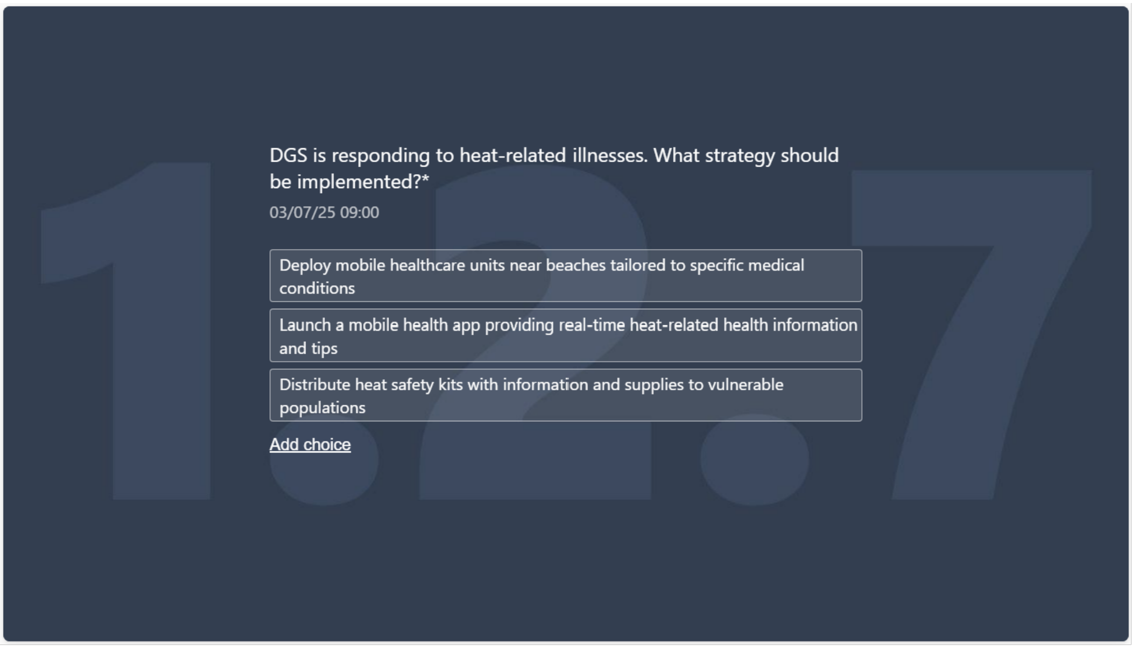

Figure D.3: Example of a decision point in the Typeform platform, displaying the date and hour of the decision and the alternatives of action. Note the * at the end of the prompt that suggests this is an obligatory response.

E

Multi-Criteria Decision Analysis

Table E.1: Multi-Criteria Decision Analysis for Inject 1.

Criteria			Health Impact	Infrastructure Resilience and Adaptation	Interagency Coordination	Emergency Response	Socioeconomic Impact	Public Awareness and Education	Long-Term Sustainability	Community Vulnerability	Psychosocial Impact		
Score			0.2	0.2	0.2	0.1	0.1	0.05	0.05	0.05	0.05		
Decision	**Time**	**Option**										**Score**	**Rank**
Inject 1	*01/07/2025 06:00*							*Heatwave*					
1.1.1	01/07/2025 06:15	a	0	1	0	1	0	0	1	0	0	0.35	1
		b	0	0.5	0	0.5	0	0	0.5	0	0	0.175	2
		c	0	0	0	0	0	0	0	0	0	0	3
1.1.2	01/07/2025 09:00	a	0	1	1	1	0	0	1	0	0	0.55	1
		b	0	0.5	0.5	0.5	0	0	0.5	0	0	0.275	2
1.1.3	01/07/2025 11:00	a	0	1	1	1	0	1	1	0	1	0.65	1
		b	0	0.5	0.5	0.5	0	0.5	0.5	0	0.5	0.325	2
		c	0	0	0	0	0	0.5	0	0	0	0.025	3
		d	0	0	0	0	0	0	0	0	0	0	4
1.2.1	01/07/2025 16:00	9-10	1	0	1	1	0	1	1	1	1	0.7	1
		7-8	0.75	0	0.75	0.75	0	0.75	0.75	0.75	0.75	0.525	2
		5-6	0.5	0	0.5	0.5	0	0.5	0.5	0.5	0.5	0.35	3
		<4	0.25	0	0.25	0.25	0	0.25	0.25	0.25	0.25	0.175	4
1.2.2	02/07/2025 09:00	a	1	1	1	0.5	1	1	1	0.5	1	0.925	1
		b	0.5	0.5	0.5	1	0	1	0.5	1	0.5	0.55	2
		c	0	0	0	0	0.5	0.5	0	0	0	0.075	3
		d	0	0	0	0	0	0	0	0	0	0	4
1.2.3	02/07/2025 14:00	a	1	1	1	1	1	1	1	0	1	0.95	1
		b	0.5	0.5	0.5	0.5	0	0.5	0	1	0.5	0.45	2
		c	0	0	0	0	0.5	0	0.5	0.5	0	0.1	3
1.2.4	02/07/2025 09:00	a	1	1	1	1	0.5	1	0.5	1	1	0.925	1
		b	0.5	0.5	0.5	0.5	0	0.5	0	0.5	0.5	0.425	2
		c	0	0	0	0	1	0	1	0	0	0.15	3
1.2.5	02/07/2025 14:00	a	1	0	1	1	1	0.5	1	0.5	0.5	0.725	1
		b	0.5	0	0.5	0.5	0.5	1	0.5	0	1	0.425	2
		c	0	0	0	0	0	0	0	1	0	0.05	3
1.2.6	03/07/2025 09:00	a	1	1	1	1	1	0	1	1	1	0.95	1
		b	0.5	0.5	0.5	0.5	0	0	0	0.5	0	0.375	2
		c	0	0	0	0	0.5	0	0.5	0	0.5	0.1	3
1.2.7	03/07/2025 09:00	a	1	1	1	1	0	0	0.5	1	0	0.775	1
		b	0	0.5	0.5	0	1	1	1	0	0	0.4	2
		c	0.5	0	0	0.5	0.5	0.5	0	0.5	0	0.25	3
1.2.8	04/07/2025 09:00	b	1	0	1	1	0.5	0.5	0.5	1	1	0.7	1
		a	0	0	0	0.5	1	1	0	0.5	0.5	0.25	2
		c	0.5	0	0.5	0	0	0	1	0	0	0.25	3

Table E.2: Multi-Criteria Decision Analysis for Inject 2.

Criteria			Health Impact	Infrastructure Resilience and Adaptation	Interagency Coordination	Emergency Response	Socioeconomic Impact	Public Awareness and Education	Long-Term Sustainability	Community Vulnerability	Psychosocial Impact		
Score			0.2	0.2	0.2	0.1	0.1	0.05	0.05	0.05	0.05		
Decision	**Time**	**Option**										**Score**	**Rank**
Inject 2	*05/07/2025 17:00*							*Drought*					
2.1	06/07/2025 09:30	a	0	0	1	1	1	1	1	0	0.5	0.525	1
		b	0	0	0	0	0.5	0.5	0	0	1	0.125	2
		c	0	0	0.5	0.5	0	0	0.5	0	0	0.175	3
2.2	06/07/2025 15:00	a	0	1	1	1	1	1	1	1	0	0.75	1
		b	0	0.5	0	1	0	0	0.5	0.5	0	0.25	2
		c	0	0	0.5	0.5	0.5	0.5	0	0	0	0.225	3
2.3	06/07/2025 18:00	a	1	1	0	1	0	1	1	1	1	0.7	1
		b	0.5	0.5	0	0	0	0.5	0.5	0.5	0.5	0.3	2
		c	0	0	0	0.5	0	0	0	0	0	0.05	3
2.4	07/07/2025 10:00	a	1	1	1	1	1	0	1	1	1	0.95	1
		b	0.5	0.5	0.5	0.5	0	0	0	0.5	0	0.375	2
		c	0	0	0	0	0.5	0	0.5	0	0.5	0.1	3
2.5	08/07/2025 15:00	a	1	1	1	0	1	0	1	0	1	0.8	1
		b	0	0.5	0.5	1	0.5	0	0.5	0	0	0.375	2
		c	0.5	0	0	0.5	0	0	0	0	0.5	0.175	3
2.6	08/07/2025 16:00	a	0	1	1	1	1	0	1	0	1	0.7	1
		b	0	0.5	0.5	0.5	0.5	0	0.5	1	0.5	0.4	2
		c	0	0	0	0	0	0	0	0.5	0	0.025	3
2.7	09/07/2025 09:00	a	1	1	1	1	1	0.5	1	1	1	0.975	1
		b	0.5	0.5	0	0.5	0	1	0.5	0	0.5	0.35	2
		c	0	0	0.5	0.5	0.5	0	0	0.5	0	0.225	3
2.8	09/07/2025 09:00	a	1	1	1	1	1	0	1	0	0	0.85	1
		b	0.5	0	0.5	0.5	0	0.5	0	0	0	0.275	2
		c	0	0	0	0	0.5	0.5	0.5	0	0	0.1	3

Table E.3: Multi-Criteria Decision Analysis for Inject 3.

Criteria			Health Impact	Infrastructure Resilience and Adaptation	Interagency Coordination	Emergency Response	Socioeconomic Impact	Public Awareness and Education	Long-Term Sustainability	Community Vulnerability	Psychosocial Impact		
	Score		0.2	0.2	0.2	0.1	0.1	0.05	0.05	0.05	0.05		
Decision	**Time**	**Option**										**Score**	**Rank**
Inject 3	*10/07/2025 17:00*							*Air Quality*					
3.1	11/07/2025 09:00	a	0.5	0	1	1	1	1	0.5	0	1	0.625	1
		b	1	0	0	0.5	0	0	0	0	0.5	0.275	2
		c	0	0	0.5	0	0.5	0	0	0	0	0.15	3
		d	0	0	0	0	0	0	1	0	0	0.05	4
3.2	11/07/2025 12:00	a	0.5	0	1	0.5	1	1	1	1	0.5	0.625	1
		b	1	0	0	1	0.5	0	0	0.5	1	0.425	2
		c	0	0	0.5	0	0	0.5	0	0	0	0.125	3
		d	0	0	0	0	0	0	0.5	0	0	0.025	4
3.3	12/07/2025 19:00	a	1	1	1	1	0.5	1	0.5	1	0.5	0.9	1
		b	0.5	0.5	0.5	0.5	0	0.5	1	0.5	1	0.5	2
		c	0	0	0	0	1	0	0	0	0	0.1	3
3.4	12/07/2025 19:30	a	0	0	0	1	1	1	1	1	1	0.4	1
		b	0	0	0	0.5	0.5	0	0.5	0	0	0.125	2
		c	0	0	0	0	0	0.5	0	0.5	0.5	0.075	3
3.5	13/07/2025 16:00	a	1	1	1	1	1	0.5	1	1	1	0.975	1
		b	0.5	0	0.5	0.5	0	0	0	0	0	0.25	2
		c	0	0.5	0	0	0.5	1	0.5	0.5	0.5	0.275	3
3.6	14/07/2025 14:00	a	0.5	0	1	1	0.5	0	0.5	1	1	0.575	1
		b	1	0	0	0.5	1	1	1	0.5	0.5	0.5	2
		c	0.5	0	0.5	1	0	0.5	0	0	0	0.325	3
		d	0	0	0	0	0	0	0	0	0	0	4

Table E.4: Multi-Criteria Decision Analysis for Inject 4.

	Criteria		Health Impact	Infrastructure Resilience and Adaptation	Interagency Coordination	Emergency Response	Socioeconomic Impact	Public Awareness and Education	Long-Term Sustainability	Community Vulnerability	Psychosocial Impact		
	Score		0.2	0.2	0.2	0.1	0.1	0.05	0.05	0.05	0.05		
Decision	**Time**	**Option**										**Score**	**Rank**
Inject 4	*16/07/2025 13:00*							*Extreme weather*					
4.1	16/07/2025 14:00	a	1	1	1	1	0	1	1	0	0	0.8	1
		b	0.5	0.5	0.5	0.5	0	0.5	0.5	0	0	0.4	2
		c	0	0	0	0	0	0	0	0	0	0	3
4.2	17/07/2025 09:00	a	0	1	1	1	1	0	1	1	1	0.75	1
		b	0	0.5	0.5	0	0.5	0	0	0.5	0.5	0.3	2
		c	0	0	0	0.5	0	0	0	0	0	0.05	3
		d	0	0	0	0	0	0	0.5	0	0	0.025	4
4.3	17/07/2025 14:00	a	1	1	0.5	1	0.5	0	1	1	1	0.8	1
		b	0	0.5	1	0	1	0	0	0	0	0.4	2
		c	0.5	0	0.5	0.5	0	0	0.5	0.5	0.5	0.325	3
4.4	19/07/2025 07:00	a	0.5	1	1	1	1	0.5	0.5	1	0.5	0.825	1
		b	0	0	0.5	0.5	0	1	0	0.5	1	0.275	2
		c	0	0.5	0	0	0.5	0	1	0	0	0.2	3
4.5	20/07/2025 16:00	a	0	1	1	1	0.5	1	1	0.5	0	0.675	1
		b	0	0.5	0.5	0.5	1	0.5	0.5	0	0.5	0.425	2
		c	0	0	0	0	0	0	0	1	0	0.05	3
4.6	21/07/2025 12:00	a	0	1	1	1	0.5	0	0	1	0	0.6	1
		b	0	0.5	0	0	1	0.5	1	0	0	0.275	2
		c	0	0	0.5	0.5	0	0	0	0.5	0	0.175	3
		d	0	0	0	0	0	0.5	0.5	0	0	0.05	4
4.7	22/07/2025 10:00	a	0	1	1	1	1	0	0	1	0.5	0.675	1
		b	0	0.5	0.5	0.5	0.5	0	0	0.5	0.5	0.35	2
		c	0	0	0	0	0	0	0	0	0.5	0.025	3
		d	0	0	0	0	0	0	0	0	0	0	4
4.8	23/07/2025 14:00	a	1	1	1	0	0	0.5	1	1	1	0.775	1
		b	0.5	0	0.5	0	0	0	0.5	0.5	0	0.25	2
		c	0	0.5	0	0	0	1	0	0	0.5	0.175	3

2023 Evidence-Based Decision Support System for Health-Climate Crisis Preparedness: A Heatwave Situation Room Bárbara Pais

NOVA SCHOOL OF SCIENCE & TECHNOLOGY